MASTER'S THESIS

Determining the nitrogen mitigation capacity of vegetative buffer strip (nature-based solutions) in the watershed of a lowland stream, the Barbierbeek, Belgium

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Vegetative buffer strips, the groundwater kidneys of a watershed

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Bepalen van de stikstof mitigerende capaciteit van een vegetatieve bufferstrook (natuurgebaseerde oplossing) in het stroomgebied van een rivier in de lage landen, de Barbierbeek, België

Vegetatieve bufferstroken, de grondwaternieren van een stroomgebied

By Simon De Paepe

Thesis presented to achieve

the degree of Master Environmental sciences

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Acknowledgment

This thesis is the final piece of a three year adventure at Open University. An adventure that was particularly instructive, broadening and which gave me the necessary scientific knowledge and skills to improve with what I love to do, environmental scientific research.
After a long search to a topic related with soil, water and climate I came in contact with the 'Vlaamse Landmaatschappij' (VLM) via the Open University (OU) who are both partners of the Co-Adapt Interreg Mers 2 Seas project.

After discussing some possible subjects with Patrick (VLM) and Liesbeth (VLM), I came into contact with the Province East-Flanders and particularly with Pieter Boets from the 'Provinciaal centrum voor Milieuonderzoek' (PCM). Pieter came up with a research idea which really interested me and the cooperation was set up.

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Last but not least, I would like to thank my parents, Jane, Walter and my friends for all the support they gave me throughout these years. Thank you Johan to guide me into and through this adventure!

Summary

Flanders is known for its large agricultural areas and its high pressure on open space. The agricultural sector has intensified considerably in recent decades, which poses challenges in terms of ground and surface water quality. The present study investigates the mitigation capacity of an existing vegetative buffer strip along the Barbierbeek with regard to leaching of nutrients via groundwater (diffuse pollution) towards the surface water of the Barbierbeek. The Barbierbeek is a category 2 unnavigable watercourse, the source is located in the Sint-Niklaas and ends up in the river Scheldt near the municipality of Kruibeke. A recent study by Boets and Poelman (2019) concluded that the current chemical and ecological water quality of the Barbierbeek does not meet all the standards set in the European water framework directive. This research is part of Water-Land-Schap project and the European Interreg Mer 2 Seas project Co-Adapt, of which Open University is part of the consortium.

The studied vegetative buffer strip is 20m wide and 180m long, which has a wooded buffer strip in the middle and a grass buffer strip on the North and South sides. To determine the mitigating capacity, the groundwater flow, oxygen levels, hydraulic conductivity were determined and a monthly sampling campaign over a period of five months (May-October) was carried out. Seven piezometers were installed, six of them within the contours of the vegetative buffer strip and one on the public domain to determine the groundwater flow. Taking into account the groundwater flow, the difference between the nitrate concentration of the piezometers that apply as the output reference (border Barbierbeek/vegetative buffer strip) and the ones that apply as input reference (border agricultural area/vegetative buffer strip) is equal to the mitigating capacity of the vegetative buffer strip .

The groundwater flow is almost perpendicular to the Barbierbeek (southern flow), but deviates in a southeastern direction when entering the vegetative buffer strip. Four out of six piezometers placed within the vegetative buffer strip were exceeding the reference value (50mg/L) for nitrate in groundwater for each sampling event, as well as the reference value for surface water of watercourses category 2 (44 mg/L). The two piezometers in which no exceedance has been registered are located at the border between Barbierbeek and the vegetative buffer strip. The reason for not exceeding the reference values for nitrate is currently not fully known. There are a some variables that should be further investigated that may cause a lower nitrate concentration: possible dilution by surface water from the Barbierbeek and the influence of the sandy clay layer at the border Barbierbeek/vegetative buffer strip. The hydraulic conductivity varies within the vegetative buffer strip due to the heterogeneously present soil matrices, thus the residence time of groundwater also differs in the different soil matrices which affects denitrification.

Denitrification and vegetation uptake of nutrients are considered the most important processes to mitigate nutrient leaching by using a vegetative buffer strip. These processes are hampered during the research period by the following factors: little leaching of nutrients from higher situated agricultural areas, low groundwater levels, too high oxygen concentrations and the possibly low amount of organic carbon in the soil layers where the groundwater was present during the measuring period. There is a low variability of nitrate concentrations in one and the same piezometers between different sampling events but differences have been measured between different piezometers. Considering these differences and the results obtained from the literature study, we conclude that the vegetative buffer strip has a possible mitigating capacity with regard to the leaching of nitrate-rich groundwater towards the surface water of the Barbierbeek. Considering the large seasonal variability in nutrient leaching and several uncertainties which have to be determined, it is recommended to continue this study for a period of at least one year. The other ecosystem services of the vegetative buffer strip, such as biodiversity and carbon sequestration, which a vegetative buffer strip generates have to be taken into account.

Samenvatting

Vlaanderen staat gekend om zijn grote oppervlaktes landbouwgebied en zijn hoge druk op de open ruimte. De landbouwsector is de laatste decennia sterk geïntensifieerd wat uitdagingen met zich meebrengt inzake grond- en oppervlaktewaterkwaliteit. Onderhavig studie onderzoekt de mitigerende capaciteit van een bestaande vegetatieve bufferstrook langsheen de Barbierbeek ten aanzien van de uitloging van nutriënten via grondwater (diffuse pollutie) richting het oppervlaktewater van de Barbierbeek. De Barbierbeek is een onbevaarbare waterloop categorie 2, waarvan de bron gelegen is in Sint-Niklaas en waarvan de monding uitkomt in de Schelde ter hoogte van de gemeente Kruibeke. Een recent onderzoek van Boets en Poelman (2019) concludeerde dat de huidige chemische en ecologische waterkwaliteit van de Barbierbeek niet voldoet aan de normen gesteld in de Europese kaderrichtlijn water. Dit onderzoek kadert in het Water-Land-Schap project en alsook in het Europees Interreg Mers 2 Zeeën project Co-Adapt waarvan Open Universiteit deel uitmaakt van het consortium.

De onderzochte vegetatieve bufferstrook is 20m breed en 180m lang dewelke in het midden een houtkant heeft en aan de noord- en zuidzijde een grasbufferstrook. Ter bepaling van de mitigerende capaciteit werd de grondwaterstroming bepaald, zuurstofgehalte, hydraulische conductiviteit en een maandelijkse bemonsteringscampagne gedurende een periode van 5 maanden (mei-oktober) uitgevoerd. Er werden hiertoe zeven peilbuizen geplaatst, zes hiervan binnen de contouren van de vegetatieve bufferstrook en één op het openbaar domein ter bepaling van de grondwaterstroming. Rekening houdende met de grondwaterstroming staat het verschil tussen de nitraatconcentratie van de peilbuizen die gelden als output referentie (grens Barbierbeek/vegetatieve bufferstrook) en de degene die gelden als input referentie (grens landbouwgebied/vegetatieve bufferstrook) gelijk aan de mitigerende capaciteit van de vegetatieve bufferstrook.

De grondwaterstroming loopt bijna loodrecht ten aanzien van de Barbierbeek (zuidelijke stroming) maar devieert in de vegetatieve bufferstrook naar een zuidoostelijke richting. Van de zes geplaatste peilbuizen binnen de vegetatieve bufferstrook werd er bij vier peilbuizen bij iedere bemonstering de norm (50mg/L) voor nitraat in grondwater overschreden alsook de norm voor oppervlaktewater voor waterlopen van categorie 2 (44 mg/L). De twee peilbuizen waarin er geen overschrijding is vastgesteld zijn gelegen op de grens Barbierbeek en vegetatieve bufferstrook. De reden voor de niet overschrijding van de normen voor nitraat is op vandaag onduidelijk. Enkele variabelen dienen verder onderzocht te worden dewelke mogelijks een lagere nitraatconcentratie veroorzaken: mogelijke verdunning door oppervlaktewater vanuit de Barbierbeek en de invloed van de zandige kleilaag op de grens Barbierbeek en vegetatieve bufferstrook. De hydraulische conductiviteit varieert binnen de vegetatieve bufferstrook door de heterogeen aanwezige bodem matrixen, aldus verschilt ook de verblijftijd van grondwater in de verschillende bodemmatrixen wat denitrificatie beïnvloedt.

Denitrificatie en vegetatieve opname van nutriënten worden beschouwd als de belangrijkste processen om nutriënten uitspoeling te mitigeren via een vegetatieve bufferstrook. Deze processen worden belemmerd tijdens de onderzoeksperiode door volgende factoren: weinig uitspoeling van nutriënten afkomstig van hoger gelegen landbouwgebied, lage grondwaterstanden, te hoge zuurstofconcentraties en het mogelijks laag gehalte aan organische koolstof in de bodemlagen waar het grondwater tijdens de onderzoeksperiode aanwezig was. Er is een kleine variabiliteit in nitraatconcentraties in éénzelfde peilbuizen tussen verschillende bemonsteringsdagen maar er zijn wel verschillen vastgesteld tussen de peilbuizen onderling. Rekening houdende met deze verschillen en de resultaten bekomen uit de literatuurstudie, kan er geconcludeerd worden dat de vegetatieve bufferstrook een mogelijke mitigerende capaciteit heeft met betrekking tot de uitspoeling van nitraat rijk grondwater naar het oppervlaktewater van de Barbierbeek. Gezien de grote seizoenale variabiliteit in nutriëntenuitspoeling en bepaalde onzekerheden die nog bepaald dienen te worden. Wordt er geadviseerd dit onderzoek verder te zetten gedurende een periode van minimum één jaar. Er dient ook rekening gehouden te worden met de andere ecosysteemdiensten zoals het stimuleren van biodiversiteit en koolstofsequestratie die een vegetatieve bufferstrook genereert.

1. Introduction

Flanders is an intensively used agriculture area, 46% of the total surface of Flanders is used by agriculture which represents 6,279km² (Vlaanderen, 2019). Last decades, the intensification of agricultural activities, livestock and arable farming has posed challenges for agriculture to meet European ground and surface water standards regarding nutrients e.g., nitrogen and phosphorus[1]. Several end-of-pipe solutions and strict fertilization action plans have been implemented to meet the standards according to the European Water Framework Directive (EU FWD). Despite the efforts there are still elevated nutrient concentrations in ground and surface water that are most likely due to diffuse pollution from agriculture (Boets et al. 2019 ; Donoso et al. 2017).

It would be easy to further adapt the fertilization action plans in a straightforward way by reducing the nitrogen input on agricultural land, but this is not possible. The natural reactive nitrogen sinks and sources are not sufficient enough to meet human needs (ENA, 2011). If we would only use the natural reactive nitrogen stock for agricultural purposes, 50% of the world population would not exist due to a lack of food (Erisman et al., 2008). The increasing population growth and consequently increasing food demand has inevitably led to the use of synthetic fertilizer. To meet human demand, the production (Haber-Bosh process) and use of synthetic fertilizer increased strongly since the industrial revolution (Smil, 2001 ; Erisman et al., 2008). Also organics fertilizer are applied to agricultural fields. Organic fertilizer works less quickly then synthetic fertilizer but it works longer over time. The use of different fertilizer has inevitable led to land degradation.

Land degradation is defined as the undesired degradation of land due to human interventions (Keestra et al., 2018). Land degradation can be caused in different ways:

- Chemical degradation: excessive use of nutrients causes degradation of soil, ground and surface water quality;
- Physical land degradation: by using heavy machinery the upper part of the soil matrix becomes a hard crust, compaction. Compaction causes lower infiltration rates which causes drought of the soil matrix (lower phreatic groundwater level) and run-off (Keestra et al., 2018);
- Biological land degradation: by ploughing soil, organic material is oxidized which causes losses of CO_2 (greenhouse gas) to the atmosphere (Keestra et al., 2018). Less organic matter means less electron donors available for oxidation processes and a less stable fertile soil by reducing the negatively charged effective surface of the soil to witch positive charged particles (soil minerals) can bind.

The nitrogen pollution in surface water has international importance, since rivers do not stop at borders. Responses to mitigate land degradation processes and improving water quality are therefore needed not only at local level, but also at national, European and global level. Different instruments are implemented to prevent land degradation and to become or maintain a good chemical and ecological state in ground and surface water, for example the sustainable development goals (SDGs) of the United Nations.

Land degradation and water quality are high on the agenda of policy makers. In 2015 the United Nations adopted the 2030 agenda for sustainable development. A set of 17 sustainable development goals (SDGs) with 169 targets that can be used as a compass to tackle challenges as poverty, education and the climate crisis by 2030 (United Nations, 2020). Two SDGs described by the United Nations (UN) (2020) which include less land degradation and a better water quality are taken into account in this research:

1. SDG 6 ' Water and sanitation: 'Ensure availability and sustainable management of water and sanitation for all'. 3 targets set by the UN are relevant for present study. Target 6.3: 'By 2030,

[1] The research focuses only on nitrate, as phosphorus accumulates easily in the soil and is barely soluble (ecopedia, 2020). Current legislations focuses mainly on nitrate.

improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally'. Secondly target 6.6: 'By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. Thirdly target 6.b: 'Support and strengthen the participation of local communities in improving water and sanitation management'.

2. SDG 15 'life and land' as: 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss'. Land degradation is specifically proposed as target 15.3. The UN (2020) describe the target as: 'combat desertification, restore degraded land and soil, including land affected by desertification, droughts and floods, and strive to achieve a land degradation-neutral world'.

Implementing targets only based on scientific knowledge and political decisions without consulting stakeholders values and interests causes non-socially supported solutions which is an unsustainable decision.

When science and society meet, problems occur from time to time. Society for example farmers and scientists have their own storylines, their own idea of interpreting an environmental problem. They base their way of thinking/point of view on their own facts and values. Facts and values which are based on their own knowledge, interests and goals to reach. A solution must be sought from a common point of view, a co-creation.

Co-creation is based on cooperation between stakeholders, policymakers and scientists in the concept of adaptation pathways to achieve sustainable supported results (OU, 2019). Co-creation can contribute to a greater stakeholder awareness, social-robust and socially supported solutions. The underlying mechanisms of co-creation are informing stakeholders, sharing knowledge and set up dialogues to become a socially supported solution. If an environmental problem is understood by involved stakeholders they become more attached with the problem at stake. If a solution has to be elaborated it will be sooner accepted by the stakeholders. The process of working towards a solutions should be done transparent in co-creation with the involved stakeholders: farmers, local inhabitants, local authorities, nature associations… Actions are thus taken from a collective point of view which stimulates a personal feeling of responsibility and connection with the project

Solutions solving a socio-economic-environmental problem as land degradation or ground and surface water pollution are possible by using nature as a sustainable partner (Van Raaij, 2020), for example by implementing nature-based land development measures. Vegetative buffer strips and wetlands are both examples of landscape and soil-vegetation solutions.

Intertwining co-creation and nature-based solutions based on land management can provide a solid ground to build a sustainable and socially accepted solution to reach the targets set in SDG 6 and 15 and other targets set in local, national or European legislations for example improving ground- and surface water quality.

2. Nature-based solutions in land management

2.1 Nature-Based Solutions

Nature-based solutions are sustainable land development measures which are able to support and improve ecological and biochemical subsystems of our ecosystem.

`Solutions which are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.' (European Commission, n.d.)

'Restoration and rehabilitation strategies that are based on natural process and cycles are sustainable as they use natural flows of matter of energy, take advantage of local solutions and follow the seasonal and temporal changes of the ecosystems.' (Meli et al., 2014).

Nature based solutions can offer sustainable solutions or management to solve socio-economic-environmental problems and can be a successful strategy to restore degraded ecosystems. Working together with nature can result in a less maintenance sensitive system and offers more cost-effective solutions (Kabish et al. 2019). Keestra et al. (2018) mentions that solutions can be elaborated on a landscape or soil-vegetation level.

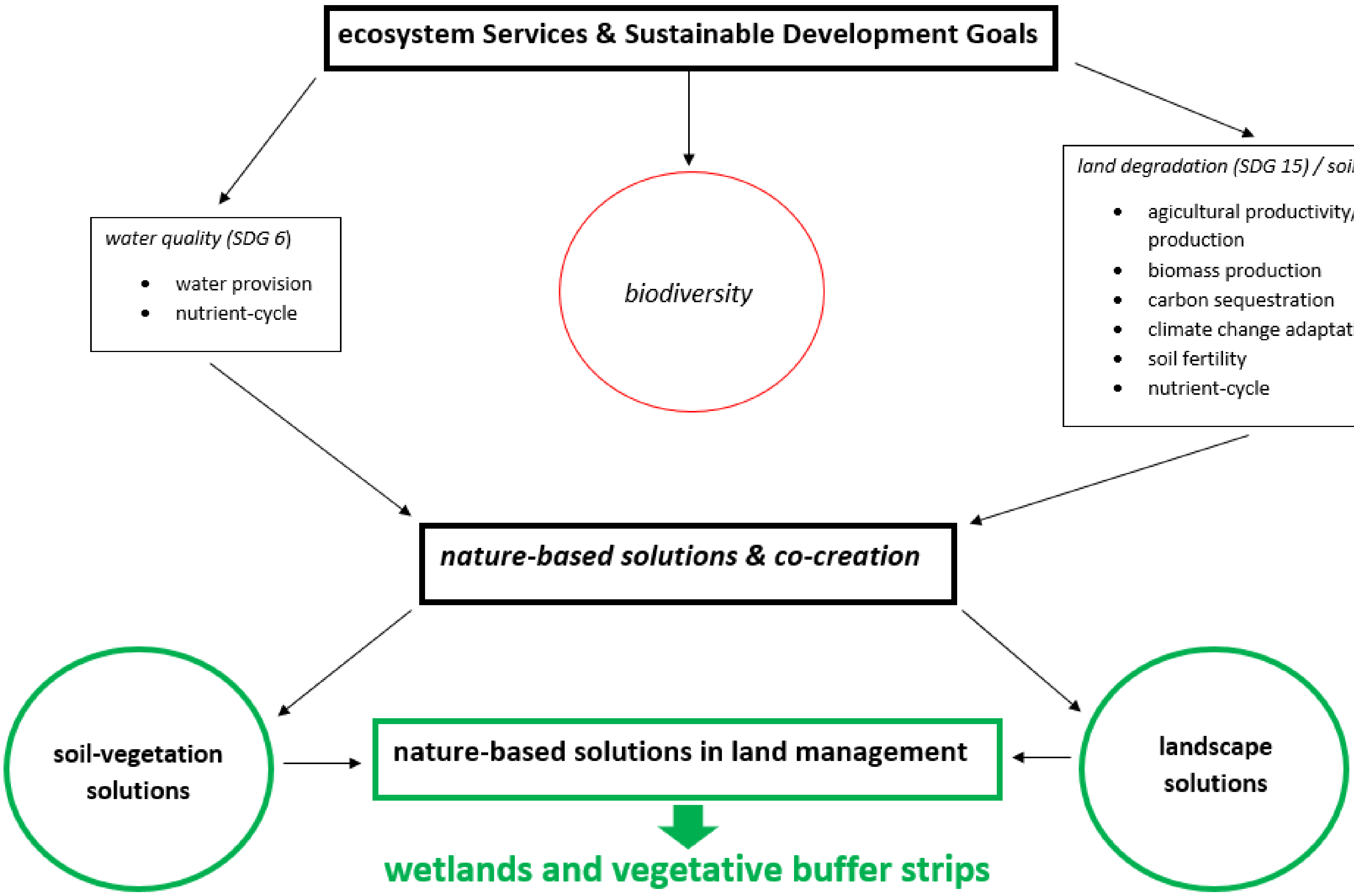


Fig. 1 : Conceptual framework adapting nature-based solutions and co-creation to tackle ecosystem services problems and to support SDG 6 and 15.

2.2 Wetlands

Constructed wetlands are widely used across the world to treat wastewater, but are not or barely used to mitigate diffuse nitrogen pollution. Wetlands are able to reduce nitrogen by serval processes: sedimentation (Karr and Schlosser, 1978; Johnston, Bubenzer, Lee, Madison and McHenry, 1984), adsorbing nutrients to sediments (Khalid, Patrick & Delaune ,1997), taking up nutrients in plant biomass (Lee, Bentley & Amundson, 1975) and most importantly stimulating denitrification by bacteria activity (Lowrance, Todd & Asmussen, 1984). Fisher and Acreman (2004) studied 57 wetlands around the world to investigate whether wetlands are able to affect the nutrient loading of waters draining through them. The most important conclusions were:

- Riparian wetlands showed a 100% retention of total nitrogen and total Kjeldahl nitrogen;
- 75% retention of nitrate and 60 % retention of ammonium.

Wetlands have other (ecosystem)functions too: increase of biodiversity, flood control, carbon sequestration and groundwater recharge (Boets et al., 2011).

Next to the proven effectiveness of wetlands a lot of wetlands do not exist anymore and a lot of sequestered carbon has been lost by removing wetlands (change in land use). Flanders lost approximately 75% of its natural wetland habitats in the past 50-60 years, remaining only 680 km² or 5% of the surface area of Flanders (Decleer et al., 2016). 15% percent or 102km² of that lost area has been converted to urbanized area, 85% or 578km² is lost mainly by expanding agriculture, to a lesser extent by an increase in forest or wood production (Decleer et al., 2016).
Next to the possible degradation of nitrogen wetlands have multiple other regulating and cultural ecosystem services e.g., climate change, flood protection, biodiversity, recreation and cultural values.

It is not everywhere possible to restore or to construct wetlands. There are other nature-based solutions in land management, for example vegetative buffer strips which are able to mitigate diffuse nitrogen pollution.

2.2 Vegetative buffer strips

Different studies have proven that vegetative buffer strips can be an effective mitigating instrument to reduce leaching of ground- and runoff water towards a stream (Balestrini et al, 2011; Ballestrini et al., 2016; Gumiero et al., 2011; Hefteling et al., 2006 & Unger et al., 2013). The main mechanisms within a vegetative buffer strips to mitigate diffuse nitrogen pollutions towards surfacewater are uptake of nutrient rich water by plants and denitrification in anaerobic soil zones (Cole et al. 2020). Hefteling et al. (2006) mentions that there are differences in nitrogen uptake between different types of vegetative buffer strips: 38% nitrogen removal in a forested riparian buffer zone and 63% nitrogen removal in a grassland riparian buffer zone. According to Ballestrini et al. (2011), Gumiero et al. (2011), Hefteling et al. (2006) there are some environmental variables that determine the efficiency of nitrogen removal by vegetative strips e.g., groundwater level, nitrogen in flow concentrations, lithology, evapotranspiration, groundwater flow patterns, run-off, slope gradients, precipitation, amount of organic matter, speed of groundwater fluxes and seasonal variability. The effects of all these variables can fluctuate depending on the climatic conditions.

Scientific literature is not conclusive in which variables are determining and how effective a vegetative buffer strips works in case of mitigating nutrient leaching via groundwater. The determining variables for the possible mitigation capacity of a vegetative buffer strip must be studied separately for each research site due to potential geophysical and geographic differences. In this study the possibilities of nature-based solutions, specifically wetlands and vegetative buffer strips at a demarcated research location in Kruibeke will be investigated. They key to success in working with nature-based solutions like wetlands and vegetative buffer strips is knowing the processes and feedbacks of the system, system thinking (Keestra et al., 2018). Different processes within the nitrogen cycle are responsible for the mitigation via vegetative buffer strips.

3. Nitrogen cycle

The nitrogen cycle is a complex biogeochemical cycle which converts nitrogen into multiple other chemical forms as it circulates through atmosphere, soil and water systems.

Our earth's troposphere contains 78% dinitrogen (N_2), which is therefore the most abundant gas in the atmosphere. The inert dinitrogen gas is colourless, odourless, tasteless and harmless for human and environment. The inert dinitrogen gas has not much use for plants or animals, since plants need reactive nitrogen, for example nitrate. There is one exception of plants which do not need reactive nitrogen: 'vlinderbloemigen' leguminous plants. They fix nitrogen by bacterial activity (gender Rhizobium).

Different processes are present within the nitrogen cycle (see fig 2 and 3 for schematic representation):

Assimilation
Plants absorb reactive nitrogen and transform them into amino acids (assimilation). Animals on their turn eat plants as nitrogen nutrient (Tysmans et al., 2016).

Ammonification
Dead plants, plants residues, animal manure or dead animals contain nitrogen compounds and organic compounds. These compounds are broken down by bacterial activity (bacteria or and fungi) to soluble ammonium salts (Tysmans et al., 2016).

Nitrogen fixation
Nitrogen fixation is the conversion of dinitrogen (N_2) into ammonia, it is done biological and non-biological.

<u>Biological</u>
Once in the soil or surface water ammonia is formed by bacterial activity (symbiotic bacteria, anaerobic bacteria and algae) combining hydrogen with 2 nitrogen atoms (Tysmans et al., 2016).

<u>Non-biological</u>
Lighting strikes are responsible for a small amount of nitrogen fixation through high energy fixation (The Environmental Literacy Council, 2020).

Nitrification
Ammonia is used by some plants, but is mainly transformed into nitrate by bacterial activity, nitrification. Nitrification (oxidation) of ammonium to nitrite and subsequently nitrate takes place in the aerobic soil zone. The bacteria Nitrosomonas and Nitrosospira convert ammonium to nitrite, which is toxic for plants.

$NH_4^+ + 3\ O_2 \rightarrow 2H^+ + 2NO_2^- + 2H_2O$ (formation of H^+, acidifying process)

During the oxidation of ammonia (NH_4^+) to nitrite (NO_2^-) intermediate substances are formed, the intermediates are hydroxylamine (NH_2OH) as first intermediary (Bremner and Blackmer, 1981). Further formed intermediate substances are nitroxyl (NOH), hyponitrite acid ($H_2N_2O_2$), dihydroxyammonium ($(NH(OH)_2)_2$), nitrodyroxylamine (NO_2NHOH), nitrosyl (NO^+) and nitric oxide (NO) (Deweer and Meire, 1997).

During this intermediate reactions trace gasses are formed: dinitrogen monoxide (N_2O) and nitrogen oxide (NO). N_2O is a strong greenhouse gas, it has a global warming potential over 100 years which is 310 times bigger than carbon dioxide CO_2 (Boersema and Reijnders, 2010).

$NO_2^- + O_2 \rightarrow 2\ NO_3^-$ (nitrobacter)

De formation of nitrite and nitrate delivers respectively 272kJ and 79kj. Because of the low amounts of energy released and the big demand of energy for the synthesis of cell material, the cell grow is low. That is why nitrification is a slow process within the nitrogen-cycle (Deweer and Meire, 1997).

Denitrification

The dentification process requires oxygen levels lower than 0,2mg O_2/l. This conversion is done by heterotrophic (oxidation organic material) and autotrophic bacteria, bacteria use nitrogen as electron acceptor (Tysmans et al., 2016). Denitrification processes takes primarily place in wet anaerobic soils.

$2NO_3^- \rightarrow \mathbf{2\ NO_2^-} \rightarrow \mathbf{2NO} \rightarrow \mathbf{N_2O} \rightarrow \mathbf{N_2}$

Examples of denitrifying bacteria are:

- Paracoccus denitrificans (autotroph, oxidation H_2) (Zumft, 1997);
- Thiobacillus denitrificans (autotroph, oxidation H_2S, oxidation S) (Zumft, 1997);
- Pseudomonas stutzeri (heterotrophic, oxidation organic compounds) (Madigan et al. 1997).

Dissimilatory nitrate reduction to ammonium (DNRA)

Nitrate can also be removed under reduces conditions by dissimilatory nitrate reduction to ammonium (Hefteling et al. 2006). It is the results of chemoorganoheterotrophic microbes using nitrate as an electron receptor (Lam et al. 2011 ; Kraft et al. 2011).

There are some possible losses within the nitrogen cycle towards soil and water systems. Several variables determine the concentration of ammonium, nitrate and nitrite ending up in surface water:

1. Amount of applied fertilizer on agricultural land (Deweer and Meire, 1997);
2. Kind of applied fertilizer: mineral or chemical fertilizer, animal manure (Deweer and Meire, 1997);
3. Uptake of nutrients by plants;
4. The possibility and the speed at which degradation processes (nitrification and denitrification) of ammonium, nitrite and nitrate can occur.

Site-specific factors also determine losses to surface water, for example the possibility of run-off water ending up directly in surface water without being broken down.

High concentrations of nutrients in surface are causing a bad chemical and ecological status of the water system. A water system which contains high amounts of nutrients is an eutrotrophic water system.

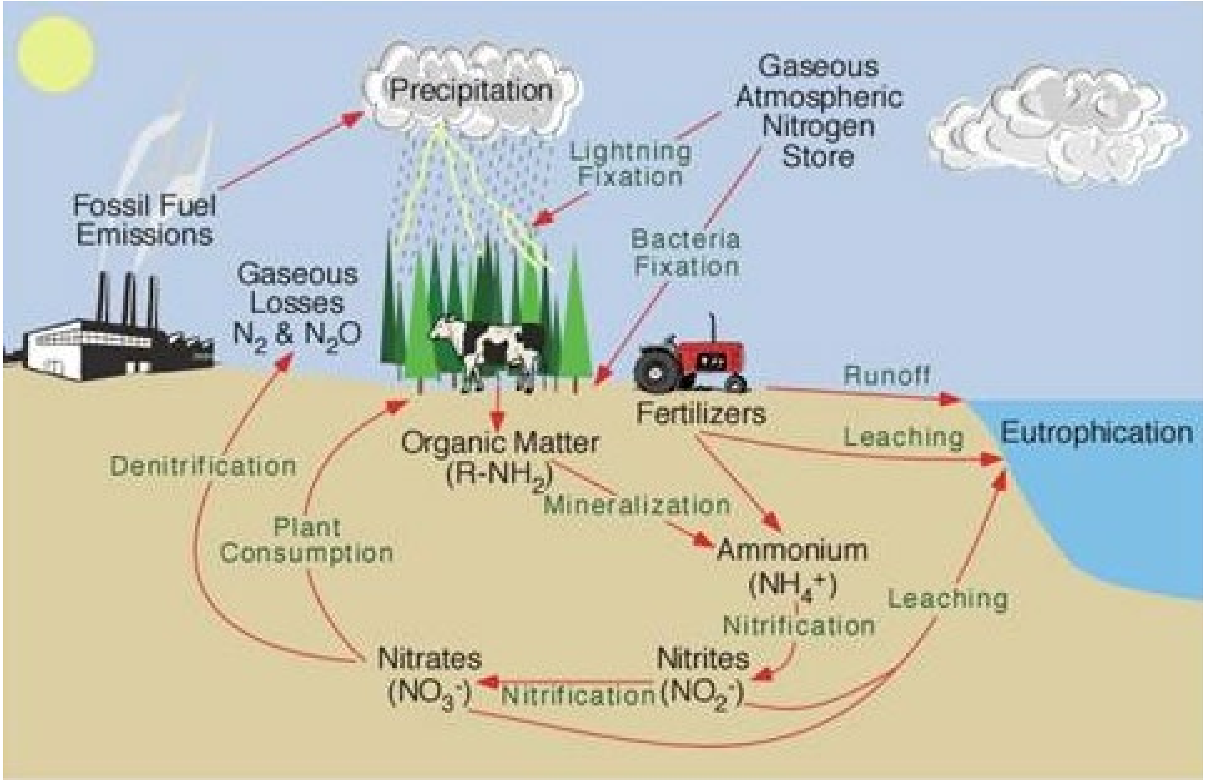


Fig. 2: Schematic representation of the nitrogen cycle (College of Tropical and Human Resources, 2020)

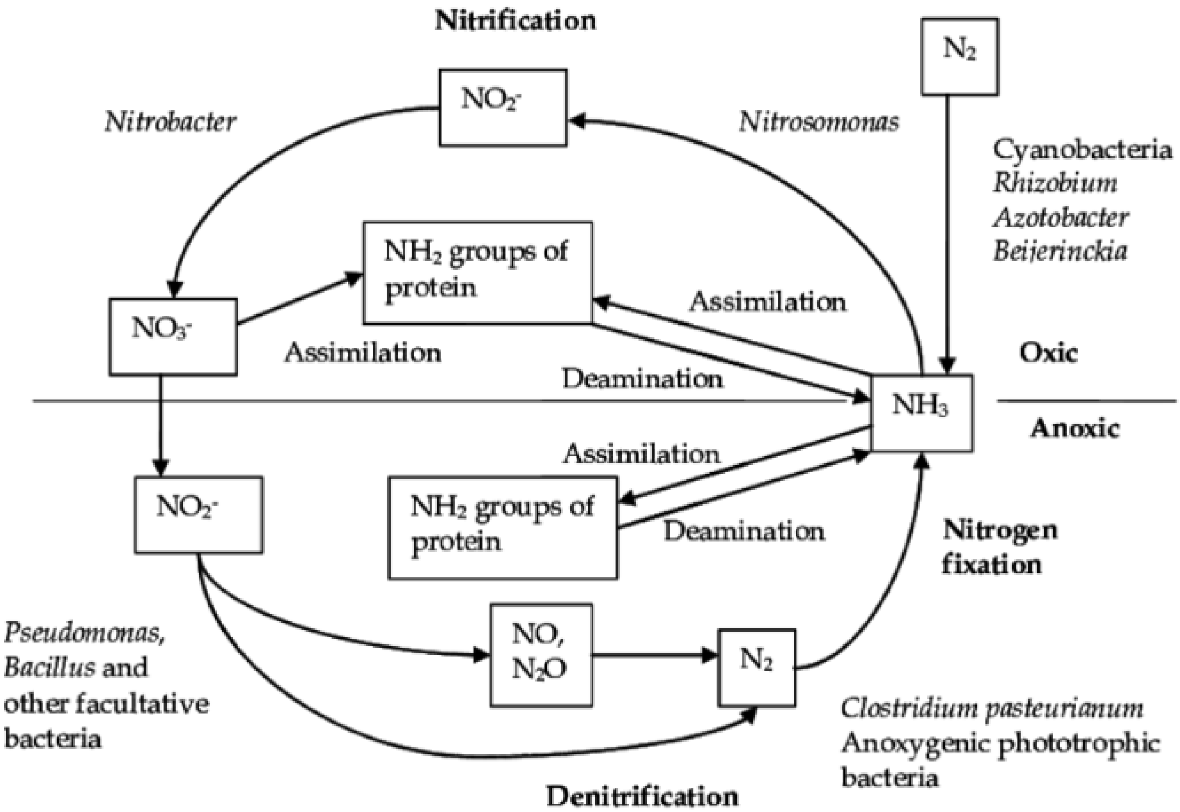


Fig. 3 Scheme of the soil nitrogen cycle: aerobic and anaerobic zone (Madigan et al. 1997)

4. Project framework

The province of East-Flanders wanted to take an extra effort near the Barbierbeek to give the stream better development prospects, for example improving the water quality in the Barbierbeek. A project was started in 2003 to evaluate which bank sides of the Barbierbeek are appropriate to create vegetative buffer strips. In 2007 the deputation of East-Flanders approved a design development plan (DDP) for the acquisition, design and management of vegetative buffer strips along the Barbierbeek. In 2008 the provincial council approved the plan for land acquisitions. The project area covers 600m buffer strip along the Barbierbeek, the project has a total surface of 1ha 89a 16ca (Province East-Flanders, 2020). Within the DDP several appropriate design measures are applied to:

- Reduce the run-off of possible nutrient rich water;
- Prevent erosion of fields and banks of water systems;
- Avoid sludge flowing towards downstream areas which will lead to unfavourable effects on water quality and cause flooding problems;
- Reducing costs and frequency of clearing the lower stream parts of the Barbierbeek;
- Protect and strengthen the small scale landscape elements close to the Barbierbeek.

In order to make the above design measures possible agricultural land must be acquired. A dialogue was started with the farmers to sell land to the province of East-Flanders on a voluntary basis, only a small part of the necessary land was acquired in this way. Most of the land was acquired via a judicial expropriation, this procedure was completed at the end of 2012. At the end of 2014 the following land development measures had been taken on the left bank of the Barbierbeek:

- Sowing grass mixture;
- The construction of a spring grid;
- Planting a new row of poplars;
- Planting of stream accompanying mixed forest;
- Planting a mixed forest to prevent bank erosion;
- Vegetative buffer strips along the Barbierbeek (part of research site location).

On the right bank of the Barbierbeek:

- Sowing grass mixture;
- The construction of a hiking trail along the Barbierbeek;
- Planting of willows to prevent bank erosion.

The land development measures were completed in 2014. In 2014, the nature section of the province East-Flanders was already occupied with creating connections between different nature areas, more specific between Sint-Niklaas and Kruibeke, more specific Kruibeke, Bazel and Rupelmonde (KBR-sigma plan inundation zone). The created vegetative buffer strips in function of the DDP was ideal in case of improving water quality for the Water-Land-Schap (launched in 2019) and Co-Adapt project. But no research had been done on the mitigation capacity of those vegetative buffer strips.

Improving water quality by using vegetative buffer strips (nature-based solution) along the Barbierbeek is done where possible in co-creation with local stakeholders (farmers, local authorities and coalitions) in order to have a social-robust solutions. But not only Water-Land-Schap adapts this methodology, so does the European Interreg Mers 2 Zeeën project Co-Adapt.

4.1 Co-Adapt and Water-Land-Schap

Both projects have similar adaptation goals besides improving the water quality: sustainable water management related to climate change, improving water quality, flood reduction, sediment catchment… Adaptation pathways within both projects are based on nature-based solutions.

Co-Adapt consortium consist of various international partners. All partners are using co-creation and nature-based solutions as starting point to tackle environmental problems (VLM, 2020). VLM is a partner of the CO-adapt project but also a partner of the program team in the Water-Land-Schap project. All members of the program team share their knowledge with the initiators.

Water-Land-Schap collected initiatives to tackle water-related problems in agricultural areas, 14 projects/areas were retained (Vlaamse Landmaatschappij, 2020b). Via the European Interreg 2 seas Mers Zeeën project, Co-adapt has selected 4 of the 14 areas to set up demonstration projects to elaborate climate adaptive measures by using co-creation. The 4 selected areas are: Barbierbeek, Maarkebeek, Robuuste waterlopen Westhoek and Gaverbeekvisie (Vlaamse landmaatschappij, 2019). This research focuses on the area Barbierbeek, the established project near the Barbierbeek is called the 'Barbierbeek Verbindt'

4.2 The 'Barbierbeek Verbindt'

One of the main goals in the 'Barbierbeek verbindt' project is by co-operating or by co-creating together with local stakeholders (farmers and local authorities), achieving a good chemical and ecological status of the surface water in the Barbierbeek and its tributaries (Boets et al., 2019).

Demonstration projects are used as instruments to achieve goals. A demonstration project has been submitted concerning the catchment area of the Barbierbeek which consists 5 different demonstration measures. This research focuses on demonstration measure 5.

5 Demonstration measures:

1. Demonstration measures management
2. Support for collaboration for group management
3. Implementation works: restoration and construction of small landscape elements
4. Demonstration moments and information evenings
5. **Influence on water quality**

On 29 may 2020, these demonstration measures were approved by the planning guidance group and the minister (Province East-Flanders, 2020).

The watershed of the Barbierbeek is also selected in the river basin management plan of the Benedenscheldebekken as focus area of the Zeeschelde with the Sigma flooding area Kruibeke-Bazel-Ruppelmonde and the Getijdedurme (Vlaamse overheid, 2018, p.268). In this project the water quality of the Barbierbeek is also selected as focus point. The other focus points are:

- Fish migration, selected as focus points in the river basin management plan of the Benedenscheldebekken (Vlaamse overheid, 2018);
- Importance of the drainage function with a large drainage area of 3427ha (Vlaamse overheid, 2018, p. 193);
- A big part of the valley is a natural flooding area (Vlaamse overheid, p.193, 2018).

But how is the chemical and ecological status of the surface water in the Barbierbeek?

4.3 Water quality Barbierbeek

The 'Vlaamse Milieumaatschappij' (VMM) is responsible in Flanders for the regular sampling network and follow up of the water quality, last years the network of standard measuring points has been reduced, as it was also the case in the watershed of the Barbierbeek. Besides the fact that the Barbierbeek is a focus area in multiple projects (Co-Adapt, Water-Land-Schap…) Boets et al. (2019) conducted a research to get a better picture of the water quality in the Barbierbeek than was available through the results from the regular sampling network of the VMM. The research was a cooperation of the VMM and the 'Provinciaal Centrum voor Milieuonderzoek' (PCM).
Several conclusions have been made by Boets et al. (2019), starting upstream towards downstream:

- Near the of the Ringdijk, just before the Barbierbeek enters the flood zone, high biological oxygen demand (BOD) was registered, possibly caused by the upstream stormwater discharge overflow;
- Near of the Houtenkruisstraat, impurified household wastewater and wastewater of a nearby poultry slaughterhouse streams directly into the Barbierbeek due to insufficient functioning of the wastewater treatment plant;
- In a tributary of the Barbierbeek, near the Hoogkamerstraat in Temse, impurified household wastewater flows directly into the river. Aquafin has communicated towards Boets P. that in a short period of time a disconnecting will take place;
- In September 2019 near the Burmtiendestraat, Pachtgoedbeek a high concentration of nutrients was measured. Two possible reasons are mentioned by Boets et al. (2019): long periods of drought which causes a strong enrichment of nutrient and a possible point pollution of wastewater.

Besides to the mentioned point-pollutions, Boets et al. (2019) refers to the contribution of diffuse pollution due to agriculture activities: run-off and nutrient leaching via groundwater.

The general conclusion made by Boets et al. (2019) states that the last 3 years a declining oxygen level and a rising chemical oxygen demand (COD), nitrogen and phosphorus concentration were observed. A possible reason is given by dry and hot summers in 2017, 2018 and 2019. Which causes less growth and uptake of nutrients by plants. Drier summers also means less dilution of surface water with rainwater. When considering long term data there is a general improvement of the water quality.

Besides the phyisco-chemical water quality Boets et al. (2019) evaluated the ecological water quality (Belgian Biotic Index, BBI) and the fish stock. Concerning the ecological water quality, only in one of the recent measures a minimum score of 7 was reached. The bad scoring BBI is directly linked to the insufficient physico-chemical water quality. Recent research executed by Boets et al. (2016) shows a moderate to bad fish stock in the Barbierbeek.

Boets et al. (2019) recommends tackling the remaining discharge points and to construct buffers strips and longitudinal ditches with additional purification to reduce nutrient input from agriculture. Boets et al. (2019) refers to the importance of the Water-Land-Schap, Barbierbeek verbindt! project.

5. Research objectives

The main research objective of this study is to evaluate the mitigation capacity of a vegetative buffer strip along the Barbierbeek in order to reduce nutrient leaching via groundwater (diffuse pollution) towards the surface water of the Barbierbeek.

Therefore the thesis report will focus on the following research questions:

- What is the groundwater flow direction near the vegetative buffer strip along the Barbierbeek?
- Which soil textures are present within the vegetative buffer strip?
- Which soil textures are present near the borders of the agricultural area / vegetative buffer strip (input) and the vegetative buffer strip / Barbierbeek (ouput)?
- What are the hydraulic conductivities within the vegetative buffer strip?
- What are the hydraulic conductivities at the borders of the vegetative buffer strip: agricultural area / vegetative buffer strip and vegetative buffer strip / Barbierbeek?
- What are the oxygen levels in groundwater within the vegetative buffer strip?
- What are the oxygen levels at the borders of the vegetative buffer strip: agricultural area / vegetative buffer strip and vegetative buffer strip / Barbierbeek?
- What are the nitrate concentrations in groundwater within the vegetative buffer strip?
- What are the concentrations of nitrate at the border between agricultural area / vegetative buffer strip (input) and the vegetative buffer strip / Barbierbeek (ouput)?
- Is a nitrate concentration gradient present in the vegetative buffer strip starting from the agricultural area towards the Barbierbeek?

6. Study area

6.1 Belgium, Flanders, Barbierbeek, Kruibeke

The Barbierbeek is a strongly meandering stream located in East-Flanders on the territory of Kruibeke, Temse, Beveren and Sint-Niklaas (Coördinatencommissie Integraal Waterbeleid, 2017; Vlaamse overheid, 2018, p.193) . The source, located in Sint-Niklaas, is situated in a 'NatuurVerWervings Gebied' (NVWG) and bird- and habitat directive area (Geopunt, 2019 ; DOV Vlaanderen, 2019). The Barbierbeek flows through Temse and Beveren via the polders towards the mouth in Kruibeke, ending up in the River Scheldt (Coördinatencommissie Integraal Waterbeleid, 2017). The downstream part between the motorway E17 (Gent-Antwerp) and the mouth in Kruibeke is defined as protected landscape.
The Barbierbeek is a non-navigable watercourse category 2 managed by the province of East-Flanders. The Barbierbeek is mainly a rain water fed river and during heavy rainfall the water level can rise very quickly leading to possible inundations.

Different landscapes are present in the Barbierbeek valley: forests, grasslands and mostly maize fields (Vlaamse overheid, 2018). The bigger part of the land use near the Barbierbeek is agriculture.

The topographic watershed of the stream together with the characteristic convex fields, form the spine of the natural connection between Scheldt and Durme valley and the forest cores on the Zuidzandrug Waasmunster-Beveren (Vlaamse overheid, 2018, p.193).

6.2 Topographic watershed of the Barbierbeek

What is a topographic watershed?
According to Tysmans et al. (2016) a topographic watershed can be described as: "an area where all water running over the surface flows through a series of storms, rivers and possibly lakes into the sea through one estuary." A watershed therefore consist of a valley floor, a river, the valley walls and those parts of the interfluve that drain to the valley.

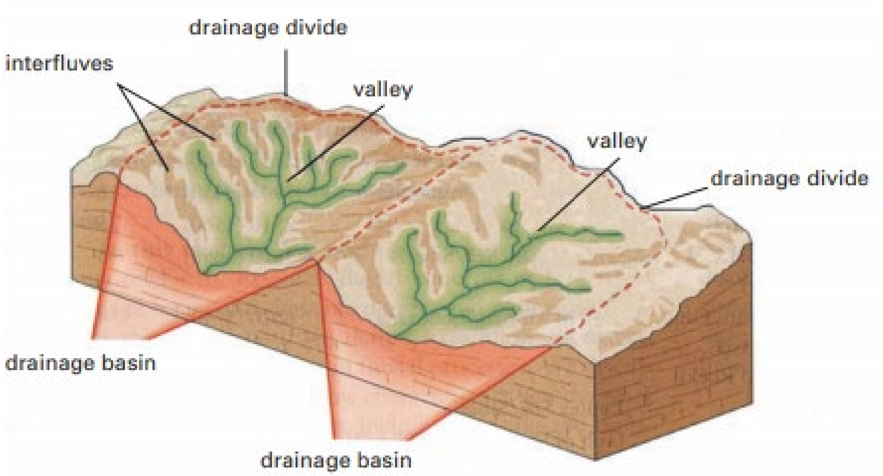


Fig. 4: Schematic representation of a topographic watersheds with indication of all the different elements within a topographic watershed (source: Christopherson (2009)).

The topographic watershed of the Barbierbeek and the subareas within the entire watershed are determined via QGIS 3.4 Madeira. By selecting the layers 'watersheds' and the digital terrain model (DTM) model the watersheds are determined.

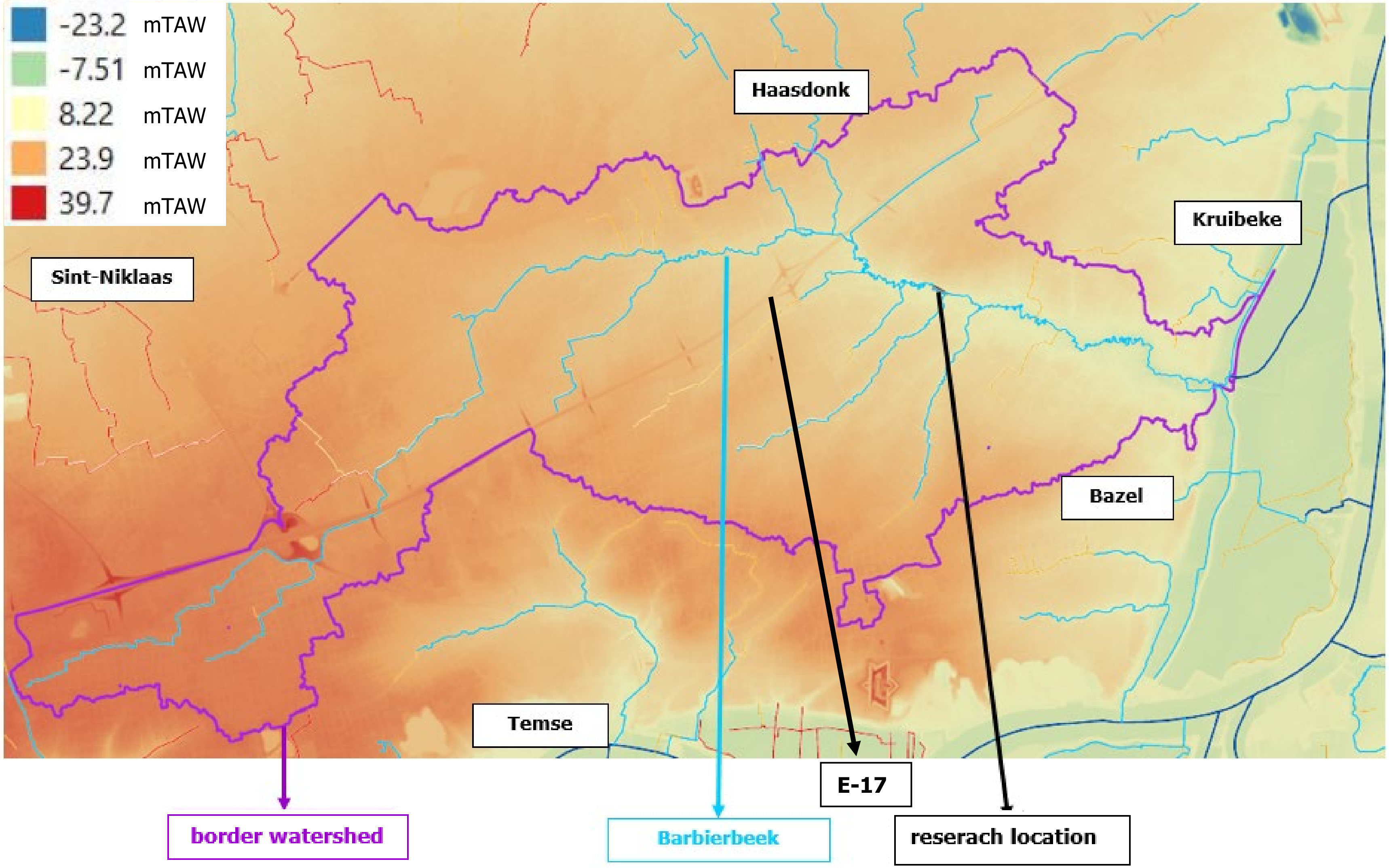


Fig. 5: Entire watershed of the Barbierbeek with terrain model background and indication of the cities as well as the research location.

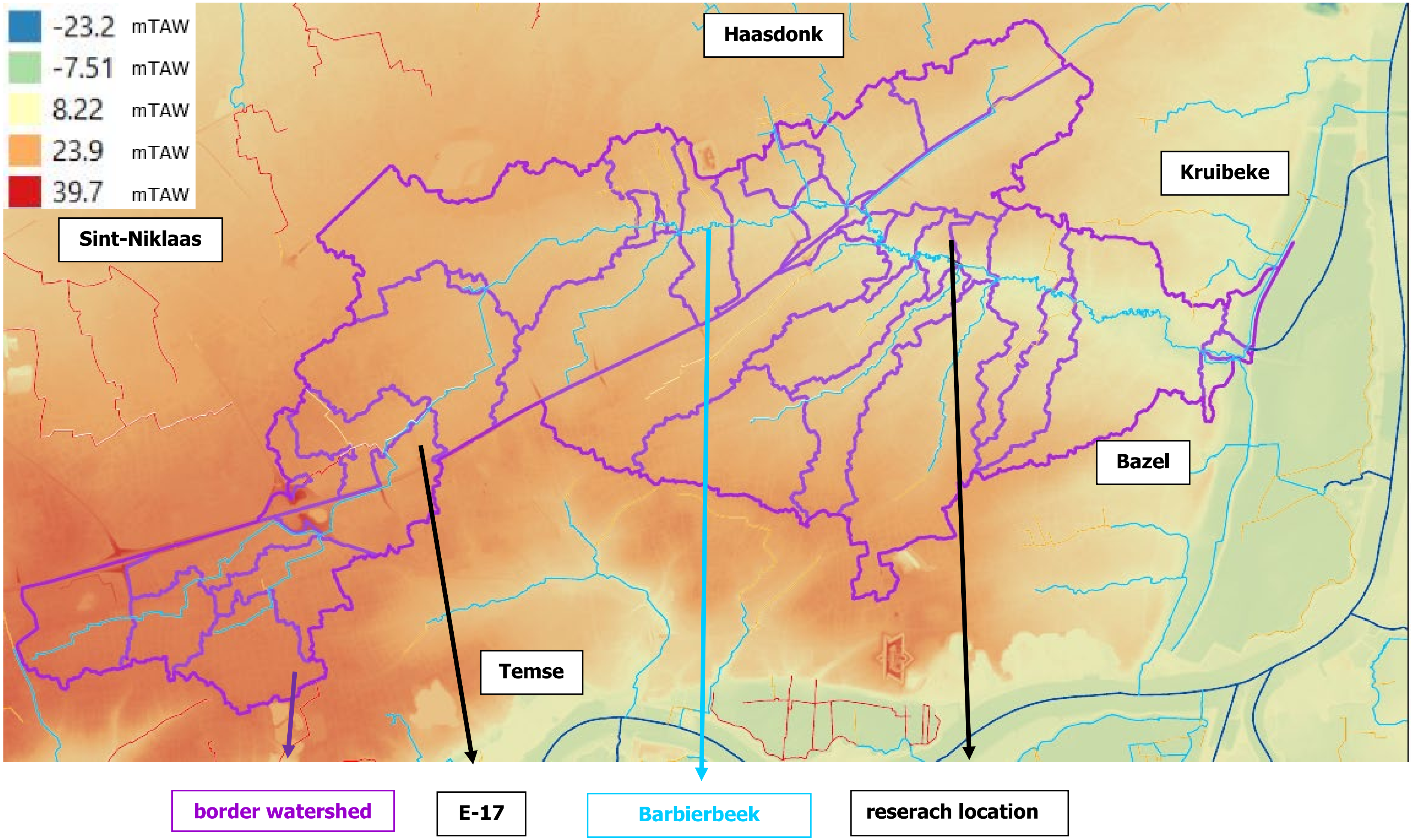


Fig. 6: Enitre watershed of the Barbierbeek divided in differend sub-watersheds with terrain model background and indication of the cities as well as the research location

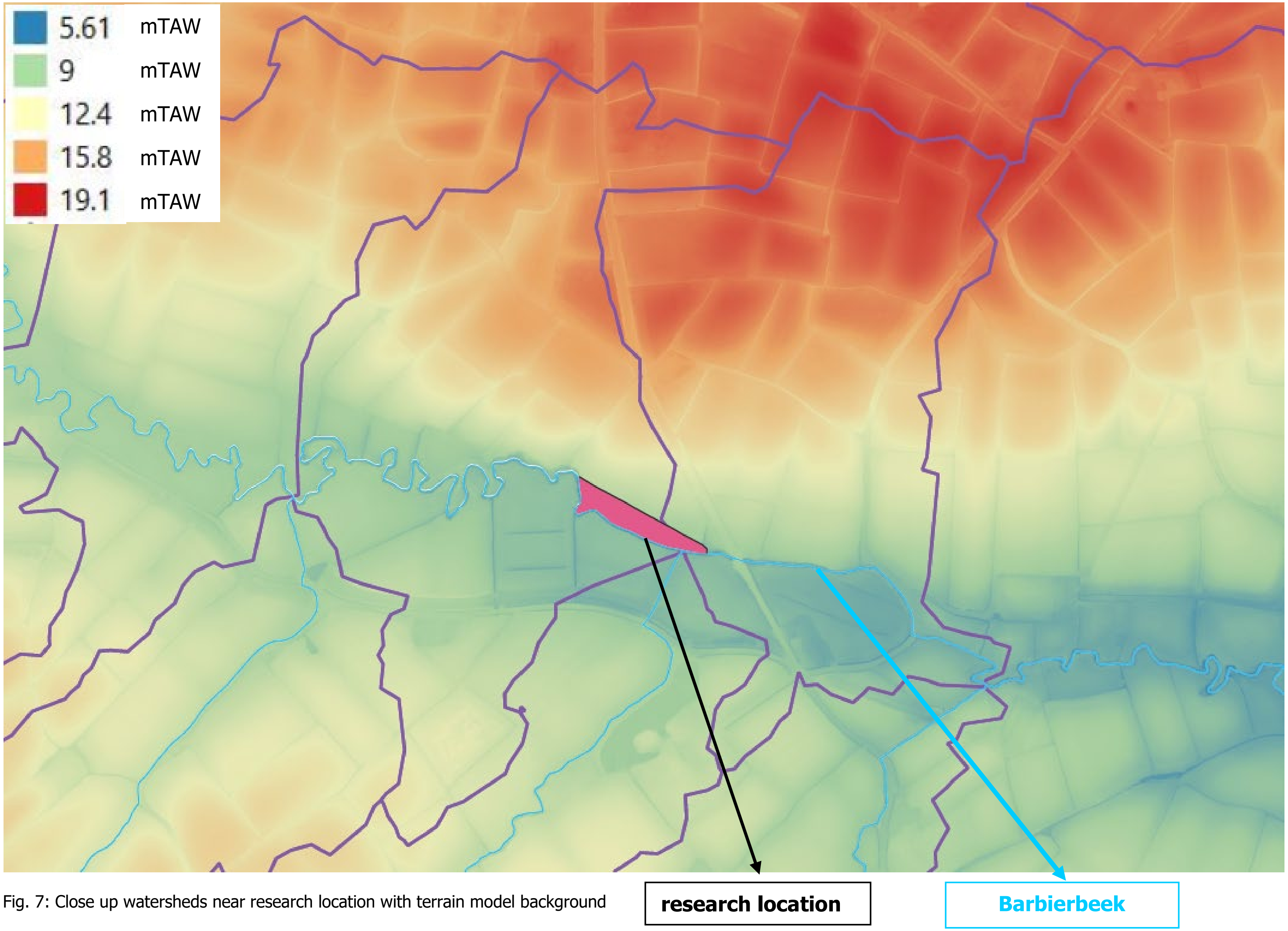


Fig. 7: Close up watersheds near research location with terrain model background

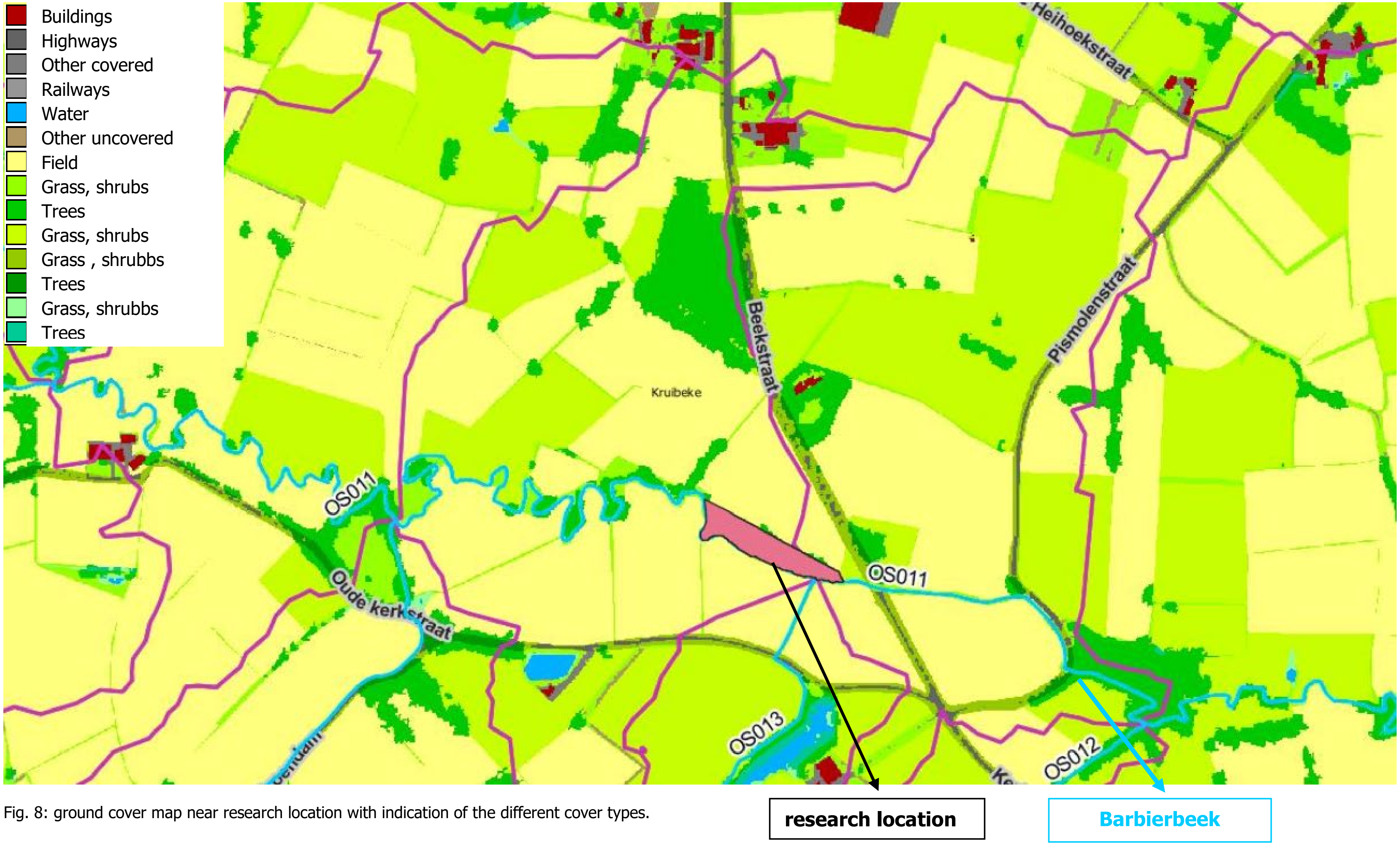


Fig. 8: ground cover map near research location with indication of the different cover types.

6.3 Climatic conditions

According to the Royal Meteorological Institute 'Koninklijk Meteorologisch Instituut' (KMI) Belgium has a temperate climate characterized by fresh and humid summers and relatively mild and rainy winters but with possible exceptions in both winter and summer. Belgium has an average of 1.400 to 1.700 hours of sunshine (Kruibeke 1.635), the average precipitation amount in Belgium is 925 mm/year (Kruibeke 859.3 mm/year) (ww.meteo.be). The average temperature over the year is 10.6 °C.

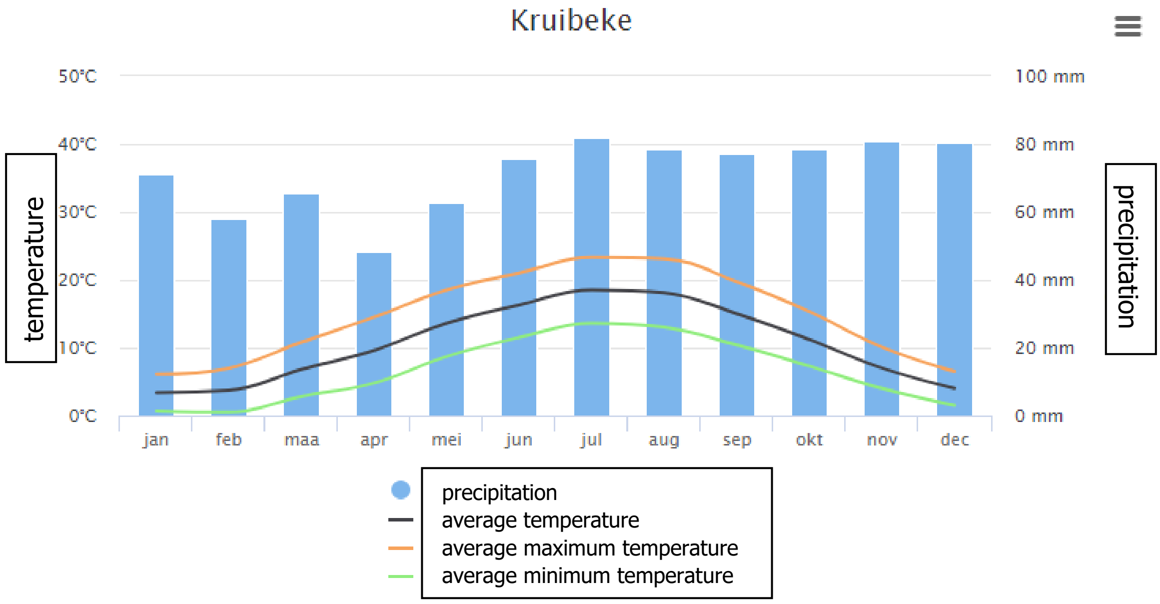


Fig. 9: Kruibeke (NIS 46013), retrieved from https://www.meteo.be/nl/klimaat/klimaatatlas/klimaat-in-uw-gemeente

6.4 Hydrogeological buid-up

The hydrogeological build-up in Flanders can be divided in 6 groundwater systems and 42 groundwater bodies, this distribution is inspired on the European Water Framework Directive. Flanders is build up in regional differing aquifers (sand, gravel, chalk,…) and aquitards (clay). The sequence of these layers is represented in Flanders by means of a code HVOC (Hyrdogeologische codering van de Ondergrond van Vlaanderen (Meyus et al. 2000).
The Barbierbeek is situated in groundwater body central Kempisch system with HVOC-code = CKS[2]_0200_GWL:

- Name groundwater body : central Kempisch system;
- Name groundwater system: central Kempisch system;
- Name watershed : Scheldt.

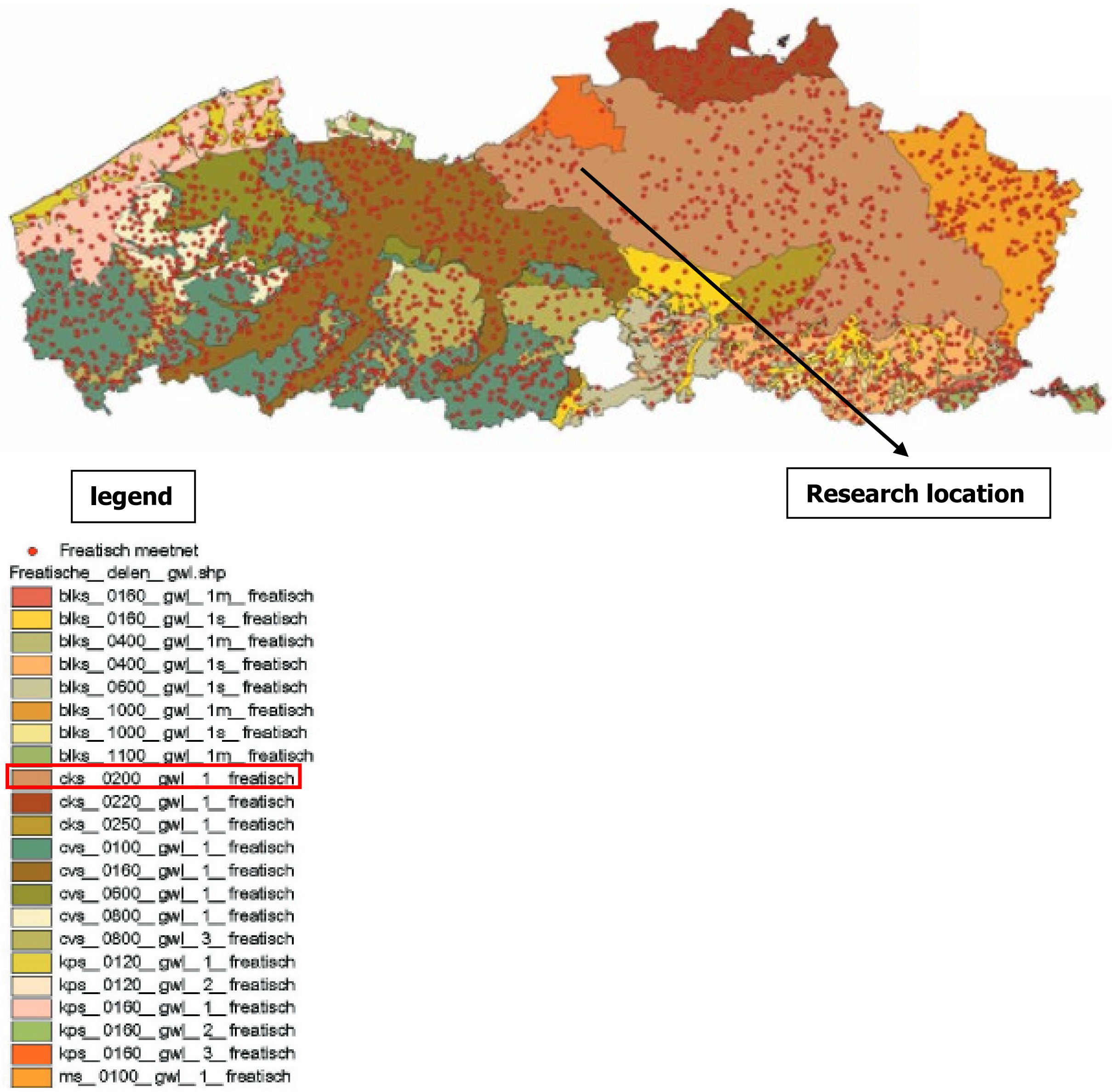
Aquifer characteristics:

- Surface = 3419km²;
- Maximum thickness = 433m;
- Lithology : sand and clay;
- Salinity : not present.

[2] Centraal Kempisch Systeem

Table 1: Different land use within the groundwater body 'central Kempisch system' (Source: Coördinateiecommissie Integraal Waterbeleid, n.d.)

Percentage of the waterbody that reaches the surface, total= 100%	
Agricultural area	49%
Forest area	16%
Urbanized area	27%
Industry	4%
Other land use	4%



freatisch meetnet= phreatic measuring network
freatisch= phreatic

Fig. 10: Phreatic groundwater bodies + measuring network (source: D'hont et al. 2007)

Geology near research location

In order to the determine the geology 3 methods are used:

1) Via the website a virtual drilling https://www.dov.vlaanderen.be/page/aan-de-slag-met-virtuele-boring can be done in order to determine the different geological layers;

Table 2: Geological 3D-model – per formation

Chronostratigraphy	**Lithostratigraphy**	**Texture**	**Max. thickness (m)**
Quarternary	Formation of Arenberg and Stokkem	Organically rich sand, gravel with peat	2,4
	Formation of Gent	Eolic cover sand	4,2
Tertiary	Formation of Boom	Clay with septaria and silt	31

2) Soil textures determined by using physical soil maps

Table 3: Soil texture at the height of the vegetative buffer strip determined by physical soil maps

Chronostratigraphy	**Lithostratigraphy**	**Texture**	**Max. thickness (m)**
Quarternary	-	Eolic cover sand	5
Tertiary	Formation of Kattendijk	Green-grey to green glauconite and clayey fine sand	4
	Formation of Boom Member of Terhagen	Grey solid clay, weakly silt	10
	Formation of Boom Member of Belsele-Waas	grey silt clay	2
	Formation of Zelzate	Alternating clay and glauconite sand and sandy clay	17
	Formation of Maldegem	Alternating clay and sandy clay	25

3) The on-site soil texture verification is done while installing the piezometers. The drill descriptions are enclosed in attachment 4.

7. Material and methods

7.1 Selection of research site location

The research site location has to fulfil several conditions:

- It must be located in intensively used agricultural area with nearby surface water as we are researching N-leaching from intensively used agricultural land into surface water;
- Nature-based solutions (vegetative buffer strip, wetlands,…) have to be present or can be created.

7.2 Determining horizontal groundwater flow

What is groundwater flow?
Groundwater flow is the displacement of 'free' water through soil. The displacement of free water is caused by difference in groundwater levels or pressure differences. Groundwater flow can be horizontal or vertical, present research only takes into account horizontal groundwater flow. Further in the report horizontal groundwater flow will be named as groundwater flow.

Below is a step by step guide how to determine the groundwater flow.
The raw data have to be determined to visualise the groundwater flow in Surfer 11:
-Measure the groundwater level in the piezometer;
-Measure how much the piezometer protrudes above ground level;
-Determine the Z-value (Lamb72) with a GPS-system with a minimum horizontal and vertical accuracy of maximum a few centimetres.

The groundwater level is determined by using a gauge.

De X-Y-Z coordinates are determined by using a receiver 'Trimble Zephyr 3 Rover' with a horizontal and vertical accuracy of 2cm and a Geo 7x appliance. When using a GPS to determine the X-Y-Z coordinates the accuracy must be within 2cm.

To determine the groundwater flow a minimum of 3 piezometers is required, installed in a triangle. When piezometers are installed in one line it is possible that the determined groundwater flow will be incorrect. Groundwater flow on the left or the right of the line piezometers cannot be measured (Fig. 11).

Fig. 11: Schematic representation how to set-up piezometers for groundwater flow determination.

The Z-values obtained are entered into the geostatistical software program (Surfer 11) to visualize data. Surfer calculates the groundwater flow by inter- and extrapolating data, surfer visualises groundwater flow by isohypses.

7.3 Determining hydraulic conductivity

Next to the direction it is also important to determine the hydraulic conductivity. The speed at which groundwater flows through the soil matrix.
The hydraulic conductivity is determined by applying the rising-head method and by adapting granulometry.

1. Rising-head method

The rising-head method is a method applicable to measure the hydraulic conductivity in a saturated zone.

To acquire the needed data, a sludge test is carried out. Below a step by step guide to do a sludge test and to calculate the hydraulic conductivity in non-intersecting piezometers, the method varies for intersecting piezometers:

-Measure the groundwater level before start of pumping;

-Completely empty the piezometer, if not possible due to a high influx. Pump out as much water as possible and register the groundwater level again, time of pumping and the amount of pumped up water;

-Register the groundwater level rise according to the time distribution table 7 in attachment 2.

After the sludge test is done the hydraulic conductivity (K) can be calculated according to the table 8 in attachment 2 (Universoil BV, 2020). The table is only applicable to non-intersecting piezometers.

The R^2 must be as close to 1 as possible. The closer to 1, the better the piezometer 'works', the better the influx of water.

2. <u>Granulometry</u>

A second way to determine the hydraulic conductivity is by adapting granulometry. When installing the piezometer a soil sample is taken at the height of the piezometer filter. A grain distribution is determined on this sample. The following grain sizes have to be determined on this sample: 2000, 1000, 500, 250, 125, 63, 45, 16 and 2µm.

While installing piezometers 5 and 6 a soil sample was taken to analyse the grain size distribution. The sample was taken between 2-3 m-GL because this is the free groundwater layer which 'feeds the piezometer filter with water. The filter of the piezometers are between 2,2-3,2 m-mv, the soil sample is not taken between 2,2-3,2 m-mv because there is a clay layer between 3-3,2 m-mv which does hardly feed the piezometer filter.

Considering the high cost to determine the grain size distribution only 2 locations were retained to do a grain size distribution. Piezometer 5 and 6 were retained for grain size distribution analysis because of their geographical location: on the side of the vegetative buffer strip (VBS) plus one close to the agricultural field (piezometer 5, input VBS) and one close to the Barbierbeek (piezometer 6, output towards Barbierbeek).

When grain size distribution is known it can be filled in according to fig. 43 (attachment 3) The spreadsheet calculates according to the following formulas the hydraulic conductivity:

Formula Hazen: $K = 0{,}0116 \times (d_{10})^2$ with K in m/d and d_{10} in mm

Formula Seelheim: $K = 0{,}003557 \times (d_{50})^2$ with K in m/d and d_{50} in mm

Both formulas have their limitations so is the formula of Hazen best applicable to homogeneously distributed sandy soils with equal grain sizes. The formula of Hazen uses d_{10}. By using d_{10} the grain size diameters with a total amount of 10 mass percent will determine the hydraulic conductivity. For example a sandy soil with little amount of loam and clay. In this soil matrix, clay will be determining for the hydraulic conductivity.

The formula of Seelheim takes into account more fine fractions as it uses d_{50} as the basis for the calculation. This formula will better applicable for loam soils with little amount of clay and sand.

For a pure clay soils the ground pores will be of less importance. Here the clay aggregates will be determining for the hydraulic conductivity.

The results must be interpreted according to the soil texture determined during the installation of the piezometers. It is therefore highly important to make a detailed drilling description while installing the piezometer.

To determine the soil texture to the grain size distribution, figure 44 (attachment 3) has to be filled in. The percentage % sand and % clay can be distracted out of figure 43 (attachment 3).

7.4 Determining ammonium, nitrite and nitrate concentrations in groundwater

In order to measure ammonium, nitrite and nitrate in groundwater piezometers have to be installed. The piezometers are installed and sampled by following the 'Compendium voor Monstername en Analyse (CMA)', more specific CMA/1/A.1 'vaste deel van de aarde' and CMA/1/A.2 'grondwater'.
Before the installation of the piezometers the following actions must be taken:

- Determination of research strategy (location and depth of piezometers, ground sampling needed? stirred or unstirred ground sampling needed?);
- Request of piping plans (via 'Kabel en Leidinginformatieportaal (KLIP)' in Flanders);
- If applicable, the necessary safety measures must be taken.

<u>Procedure installation piezometers</u>

The procedure below has been applied according to CMA/1/A.1 'vaste deel van de aarde' and CMA/1/A.2 'grondwater', which applies to Flemish territory.

The piezometers are installed manually by using an 'edelman'-drill 7 and 12cm wide. The 12cm wide drill is used as deep as possible in order to have the largest possible gravel filter around the filter of the piezometers filter which will help the influx of water towards the filter of the piezometer. If practically not possible to drill with a 12cm wide 'edelman'-drill until deepest point due to liquid texture of the soil a 7cm wide drill can be used.

When the pre-set depth of the borehole has been reached the piezometer can be installed and the description of the different soil texture layers can be made. In the present research a piezometer with an external diameter of 50mm has been used with a filter length of 1m, a filter length up to 2m can be used. The larger the filter, the more the groundwater flows into the filter, which is favourable for the groundwater sampling. The filter depth is determined by the groundwater level, the parameter to be analysed and the practical feasibility (soil textures and consistency of the soil). The finishing around the piezometer is done as follows from bottom to the top of the piezometer (see attachment4) : gravel around the filter until 20cm above the top of the filter, the rest of the drilling hole is filled up with bentonite (clay mineral with strong swelling properties). After installation the piezometer must be rinsed with a minimum of 5x the piezometer volume. The rinse water must be clear and free of sludge and sand. Subsequently, a label is applied to the piezometer indicating the piezometer number, date of installation and the influx.

The piezometers in the present study are placed non-intersecting with the groundwater level, this means that the top of the piezometer's filter is located under the groundwater level. The top of the filter is installed just under or maximum 0,5m under the groundwater level. Intersecting piezometers are only placed when there is a suspension of a polluting floating layer, for example mineral oil on groundwater.

To measure ammonium, nitrate and nitrite concentrations in groundwater 6 piezometers were installed. In first phase (15/05/2020) four piezometers were installed: number 1, 2, 3 and 4. In second phase (10/09/2020) 3 piezometers were installed: number 5, 6 and 7 (see fig. 24 and 25). Piezometer is only installed to determine the groundwater flow. Piezometer 7 will not be in present study to interpret the mitigation capacity of the vegetative buffer strip.
The piezometers were installed non intersecting with the groundwater table, the groundwater table is above the top of the filter of the piezometer. The piezometers were installed by Pieter Boets and Simon De Paepe.
The piezometers were sampled 15/06/2020 by John Bastoen (PCM) and Simon De Paepe, 13/07/2020, 24/08/2020, 21/09/2020 and 12/10/2020 the piezometers were sampled by Simon De Paepe.

See attachment 10 for localization of taken photos.

Fig. 12: Location piezometer 1
dd. 21/09/2020

Fig. 13: Location piezometer 2
dd. 21/09/2020

Fig. 14: Location piezometer 3
dd. 21/09/2020

Fig. 15: Location piezometer 4
dd. 21/09/2020

Fig. 16: Location piezometer 5
dd. 21/09/2020

Fig. 17: Location piezometer 6
dd. 21/09/2020

Fig. 18: Location piezometer 7
dd. 21/09/2020

Fig. 19: Location piezometer 1 and 2
dd. 21/09/2020

Fig. 20: Location piezometer 3 and 4
dd. 21/09/2020

Fig. 21: Groundwater sampling
dd. 21/09/2020

Fig. 22: Groundwater sampling
dd. 21/09/2020

Measured groundwater concentrations were compared to the groundwater quality standard VLAREM II attachment 2.4.1. environmental standards and environmental criteria for groundwater. In addition to these environmental quality standards, the threshold values described per groundwater body were taken into account according to VLAREM II attachment 2.4.1 article 3. When the threshold value (article 3) is determined/present for a parameter, the assessment value determined in attachment 2.4.1 no longer applies.

Drill descriptions and assessment tables are enclosed in attachment 4.

Groundwater sampling

Below is a step-by step guide how to sample groundwater in piezometers:

-Check if the piezometer is intact;
-Measure the groundwater level plus the depth of the piezometer and how far it protrudes above ground level;
-Insert a polyethylene casing (PE), stop 50cm before the end of the piezometer;
-Insert the PE into the peristaltic pump;
-Start pre-pumping while registering the groundwater level, conductivity, pH and temperature;
-The maximum flow rate is 0.1 a 0.5 l/min with a maximum volume of pre-pumping according to the lowering of the groundwater level in the piezometers:

Table 4: Maximum volume of pre-pumping according to the lowering of the groundwater level in the piezometers

Diameter Piezometer (mm)	**Lowering of groundwater level (cm)**										
	1	**2**	**3**	**4**	**5**	**10**	**15**	**20**	**30**	**40**	**50**
25	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L
28	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L	2.5L
50	2.5L	2.5L	2.5L	2.5L	2.5L	2.9L	3.4L	3.9L	4.9L	5.9L	6.9L
63	3.3L	3.4L	3.6L	3.7L	3.9L	4.7L	5.5L	6.2L	7.8L	9.4L	10.9L

Preferably the groundwater level does not drop into the filter of the piezometer. If so it has to be registered;
-Sampling can start after the prescribed volume of water is pre-pumped and the field parameters (pH, conductivity and temperature) are stable;
-The field parameters are measured with a 'doorstroomcel' / flow-through cell. Stabilisation of the field parameters is reached when:

- Deviates a maximum of 1% from the measured value for conductivity (EC) for measured values > 1000 µS/cm or deviate by a maximum of 5µS/cm for measured values ≤ 1000 µS/cm;
- Deviates a maximum of 0.1 pH unit;

- Deviates maximum 0.2°C.

-The recipients are filled with the PE tube at the bottom of the bottle, the PE is puled upwards along with the increasing volume of water in the recipients. The recipient must be completely full, no air can be present in the bottles;
-If there is a bad influx of water into the piezometer a deviation of the sampling procedure can be allowed but must be indicated in the report.

A more detailed procedure for installing piezometers and sampling groundwater in piezometers can be consulted in CMA/1/A.1 'vaste deel van de aarde' and CMA/1/A.2 'grondwater'.

Piezometers are sampled monthly and analysed on the parameter ammonium, nitrite and nitrate. The sampling of the piezometers must be done at least an entire year. By sampling groundwater during an entire year, low and high groundwater levels and seasonal variability of nutrient leaching and uptake can be taken into account.

Analyses are done by PCM. PCM is an accredited laboratory recognised by the BELAC (Belgische Accreditatie-instelling) and VLAREL (Vlaams reglement inzake erkenningen met betrekking tot het leefmilieu).

Ammonium analyses are done following the 'Compendium voor de monsterneming, meting en analyse van water (WAC)'-WAC/III/C/002.

Principle: This automated analysis method for the determination of ammoniacal nitrogen is based on the modified Berthelot reaction. Ammonia is chlorinated to monochloramine. The latter reacts with salicylate to form 5-aminosalicylate. After oxidation a green colored complex is formed. The absorbance of this complex is determined photometrically at 660 nm.

Nitrate and nitrite analyses were performed according to WAC/III/C/002

Principle: This automated analysis method for the determination of nitrite nitrogen is based on the following reactions: Diazotation of sulfanilamide and nitrite in an acid medium. Coupling of the formed diazo compound with -naphtylethylenediamine dihydrochloride to form a pink colored azo compound. The intensity of the pink color is measured at 540 nm. For the determination of nitrate, this method is based on a reduction with cadmium. The steel passes through a glass column filled with cadmium grains, resulting in a reduction of nitrate to nitrite. The nitrite (nitrite present + reduced nitrate) is then determined as described above.

Ammonium, nitrate and nitrite are all analyzed using a Skalar Segmented flow analyzer.

7.4.1 Legislation framework and reference values

At European level, water policy is determined by the European Water Framework Directive (EU WFD), with several highlighted stipulations: achieving 'good ecological status' of water bodies in a certain timeframe, drawing upriver basin management plans and the adoption of program measures. In addition, there are other directives relating to water quality, for example the Nitrate Directive (Nitrate directive 91/676/EEC, 1991). The nitrate directive protects the water quality throughout Europe by promoting good agricultural practices (Nitrate directive 91/676/EEC, 1991).
At the Flemish level both guidelines are translated into respectively the integral water policy decree and manure decree with corresponding executive orders '*uitvoeringsbesluiten*', for example VLAREM II. VLAREM II determines different water quality standards for each type of watercourse (Vlaamse Milieumaatschappij, n.d.).

More specifically, measured groundwater concentrations are compared to the groundwater quality standard VLAREM II attachment 2.4.1. environmental standards and environmental criteria for groundwater. In addition to these environmental quality standards, the threshold values described per groundwater body must be taken into account according to VLAREM II attachment 2.4.1 article 3. The threshold value (article 3) is superior to the assessment value determined in attachment 2.4.1.

According to VMM (2014) groundwater quality standards are determined on the basis of: "risk assessments and ecotoxicological approaches, based on different existing standards systems. They used the World Health Organisation (WHO) drinking water standards, the groundwater quality standards from the European Groundwater Directive, the standards from the European drinking water directive (98/83/EC), the Flemish one based on this drinking water quality standards for groundwater". The groundwater quality standards are generic and applicable for all types of Flemish groundwater.

Next to the groundwater quality standards there are background levels, these levels are conducted from results of the monitoring network for groundwater. In contrast to the groundwater quality standards, the background levels are determined to match the natural hydrogeochemical occurrence of relevant pollutants. Due to a strong external input, no background level is determined for nitrate (VMM, 2014).

In accordance with the European provisions of the groundwater directive and the water framework directive a number of substances e.g. ammonium and nitrite, are investigated whether these represent the good chemical status of a groundwater body. These value is called the threshold value. The threshold value can be seen as an action threshold. When a substance exceeds 10% of this value, action must be taken to protect human and ecosystem. For nitrate is the threshold value equal to the groundwater quality standard (VMM, 2014).

How are reference values (milieukwaliteitsnormen), background levels (achtergrondniveaus) and threshold values are comparing to each other can be seen in figure 23.

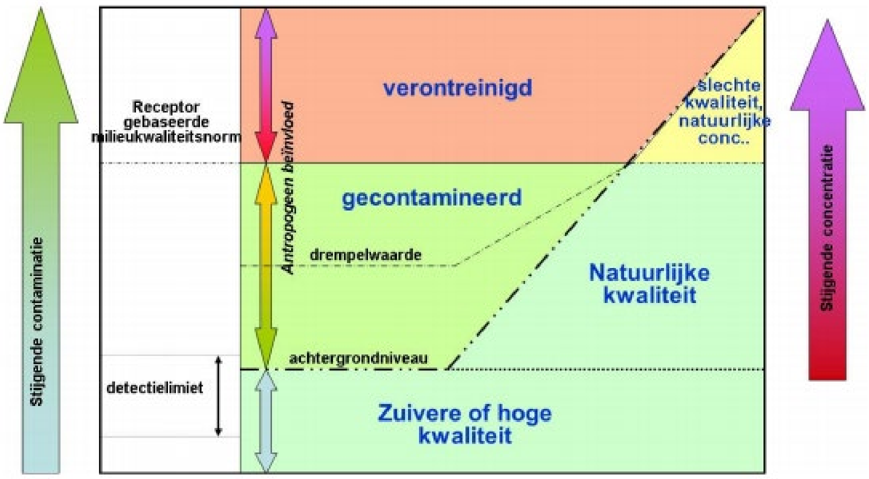


Fig. 23: Ratio between background levels, threshold values and environmental standards (source: VMM, 2014)

7.5 Determining the mitigation capacity of the vegetative buffer strip

Given the short period of research (May-October), a straightforward method is used to calculate the mitigation capacity of the VBS near the Barbierbeek. The mitigation capacity will be determined by reducing the input in the VBS of ammonium, nitrite and nitrate in groundwater by the output (see fig. 24 and 25).
The input will be determined by installing a piezometer close to the boundary of the VBS and the intensively used agricultural field. The output, near the surface water (Barbierbeek), will be measured in a piezometer as close as possible to the Barbierbeek. The hypothesis is that the difference in ammonium, nitrite and nitrate concentrations between those two piezometers is equal to the mitigation capacity of the VBS near the Barbierbeek. Between the input and output a piezometer is installed before and after the strip planted with shrubs to measure the possible mitigation capacity of the wooded buffer strip and to determine a possible difference in mitigation capacity between a gras buffer strip and a wooded buffer strip.

Two transects of piezometers are installed along the VBS (see fig. 24 and 25). A second transect has to be installed to validate the results measured in transect 1. Transect one consist of 4 piezometers (1, 2, 3 and 4), transect 2 consist of 2 piezometers (5 and 6). After consulting preliminary results, the decision has been made that a transect of another 4 piezometer was not necessary to obtain a representative result, meanwhile a cost reduction was achieved in the number of analyses and the installation of extra piezometer.

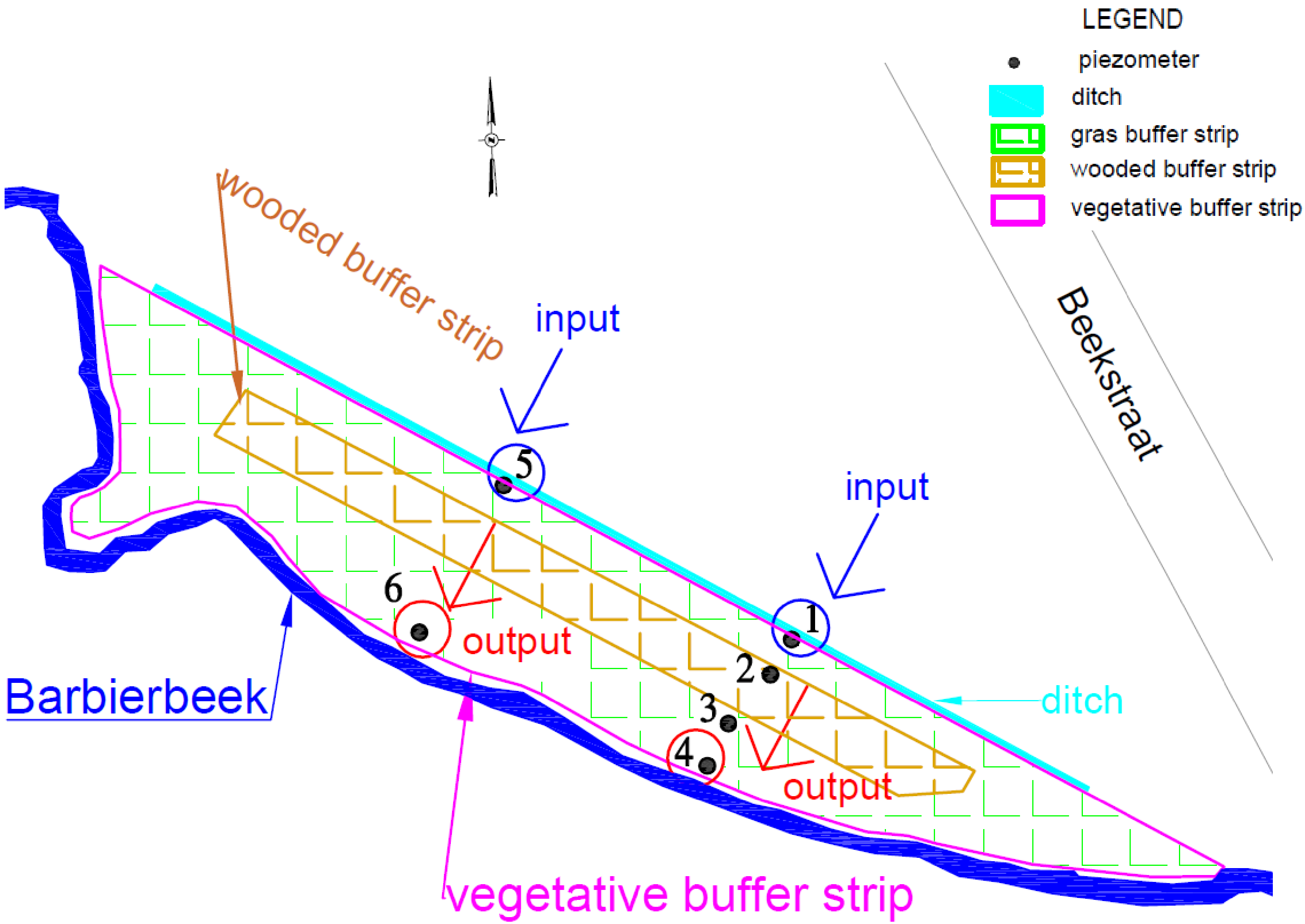


Fig. 24: Schematic representation nitrogen mitigation capacity set-up

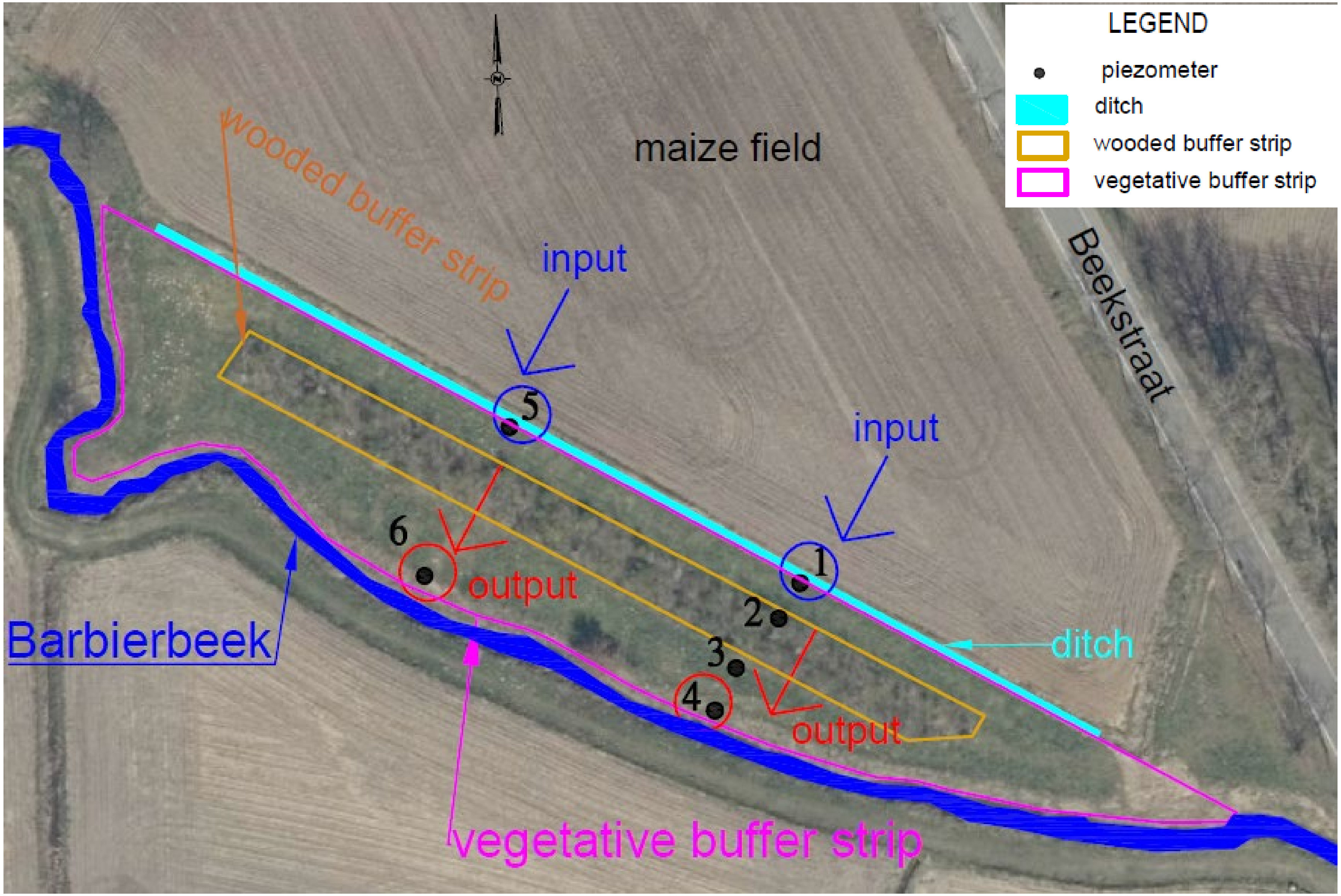


Fig. 25: Schematic representation nitrogen mitigation capacity set-up + orthographic background

8. Results

8.1 Research site selection

As mentioned in chapter 4 a vegetative buffer strip has been developed along the Barbierbeek, the vegetative buffer strip consist of two gras buffer strips with a wooded buffer strip in between, see Fig 24 and 25. The gras buffer strips consist of grasses, field thistle and sharp buttercup. The wooded buffer strip consist of hazel, hawthorn, black alder, black thorn and bird cherry. The selected research area within the vegetative buffer strip along the Barbierbeek has a surface of 3,900m² and measures 181m long and is 12m wide at the narrowest part and 38m at the widest part (see fig. 15). The gras buffer to the North of the wooded buffer strip is 5m, to the South of the wooded buffer strip between 5 and 10m. The vegetative buffer strip is located in intensively used agricultural area. The adjacent land is planted with maize.

See attachment 10 for localization of taken photos.

Fig. 26: Vegetative buffer strip (winter) dd. 7/02/2020

Fig. 27: Vegetative buffer strip (summer) dd. 21/09/2020

Fig. 28: Gras buffer strip northern part (winter) dd. 07/02/2020

Fig. 29: Gras buffer strip northern part (summer) dd. 15/05/2020


Fig. 30: Gras buffer strip southern part (summer) dd. 07/02/2020


Fig. 31: Meander Barbierbeek near research location (winter) dd. 7/02/2020


Fig. 32: Barbierbeek near vegetative buffer strip (winter) dd. 21/09/2020


Fig. 33: Barbierbeek near vegetative buffer strip (summer) dd. 7/02/2020


Fig. 34: Wooded buffer strip (summer) dd. 21/09/2020


Fig. 35: Wooded buffer strip (summer) dd. 21/09/2020

Fig. 36: Clarification of the research location by means of photos and dimensions

8.2 Groundwater flow direction

The groundwater flow is an important factor as it is an important factor to determine the mitigation capacity of the vegetative buffer strip. The nutrient rich groundwater needs to flow through the vegetative buffer strip before it ends up in the Barbierbeek. So the main mitigation processes, denitrification and nutrient uptake, can take place. If nutrient rich groundwater originating from the agricultural field does not flow through the vegetative buffer strip, the mitigating capacity of the strip is nihil.

The groundwater flow is visualised by using 'Surfer 11' (see §7.2 for more information). When the groundwater flow is visualised the isohypes are showing that the groundwater flows in a southern direction with a deviation from piezometer 1 and 5 in a more eastern direction. Considering the groundwater flow, the vegetative buffer strip can have a mitigating capacity as the nutrient rich groundwater originating from the northern agricultural field flows through the agricultural field before ending up in the Barbierbeek.

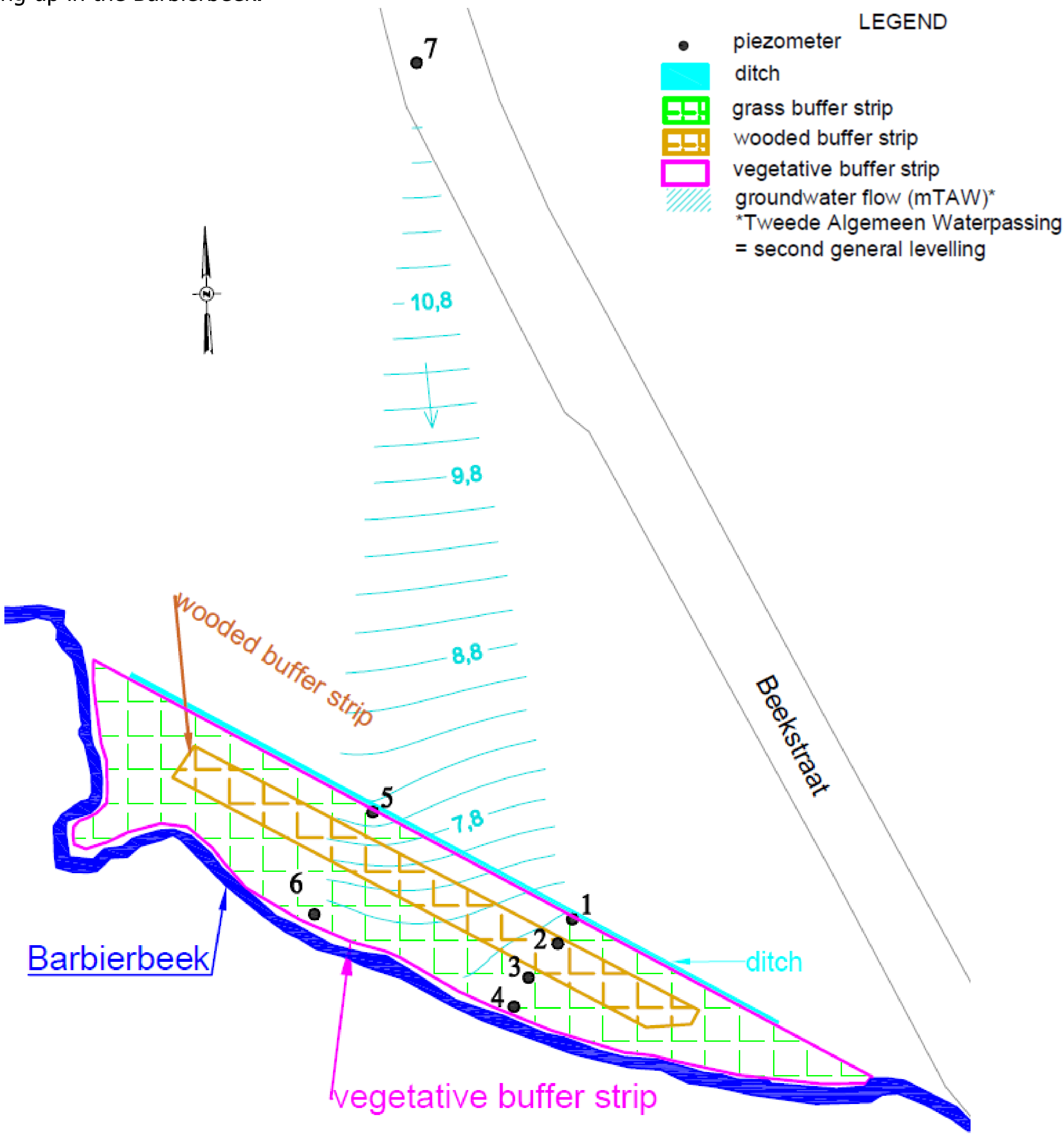


Fig. 37: Schematic representation groundwater flow near research location based on calculation by Surfer 11 software

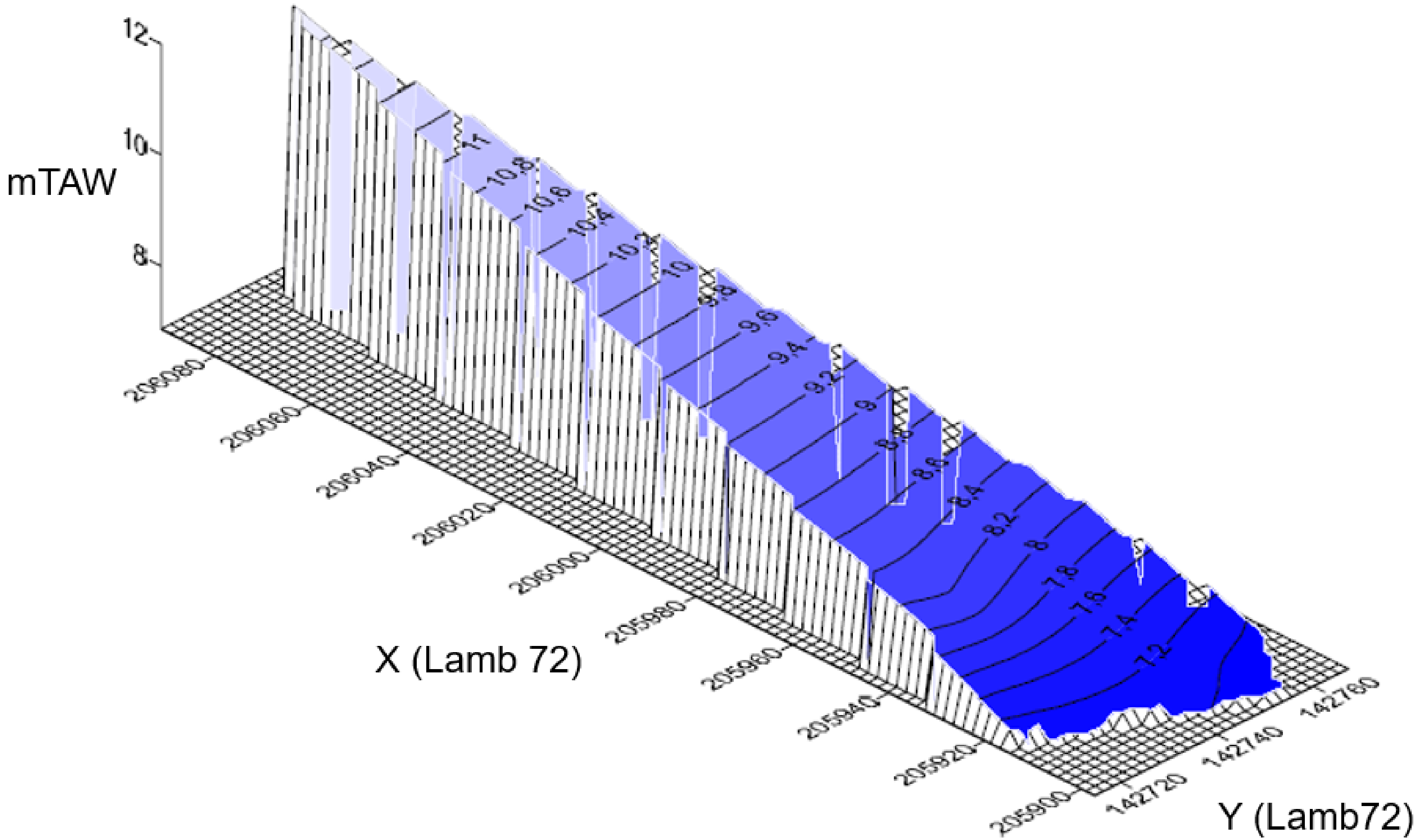


Fig. 38: 3D-representation groundwater flow near research location. 3D-model position plotted according to the Lambert 72 (Lamb72) coordinate projection system.

8.3 Hydraulic conductivity

The speed at which free groundwater flows through the soil matrix is determined by the hydraulic conductivity. This is important for the main nutrient mitigation processes: denitrification and uptake by vegetation. The longer the residence time of the nutrient rich groundwater within the vegetative buffer strip, the longer these processes can take place.

By comparing and interpreting field observations (drill descriptions, see attachemnt 4), hydraulic conductivity and the linked theoretical hyrdraulic conductivity (table 6) per soil texture, soil textures on the height of the piezometer filter were determined (see table 5).

The hydraulic conductivity is determined by applying the rising head method and granulometry. For raw data and calculations for the rising-head method and granulometry see attachment 3.

8.3.1 Rising-head method

After interpretation of the results no big differences are determined according to the rising-head method, only piezometer 2 and 5 have a slightly bigger hydraulic conductivity. During installation of piezometer 4 and 6 we perceived a sandy clay soil texture at the height of the piezometer filters.

The sandy clay layer is present at a varying dept of 2 to 3,5m-GL[3] along the border of the Barbierbeek and vegetative buffer strip. A sandy clay barrier could favour higher denitrification rates because of the lower hydraulic conductivity and the higher residence time of nutrient rich water in the soil matrix. But when evaluating the results obtained by adapting the rising-head method the hydraulic conductivity near piezometer 4 an 6 (at the height of the sandy clay barrier) are not explicit lower in comparison with the other piezometers (1, 2, 3 and 5) in the VBS. The possible influence of the sandy clay barrier on denitrification is not confirmed in this study.

8.3.2 Granulometry

Secondly granulometry is applied to compare the results with those obtained by the rising-head method. Granulometry is only applied to piezometer 5 and 6 due to the high cost of a grain size distribution analysis and because there is no added value if granulometry is applied to all piezometers.

After determining the grain size distribution (see attachment 3, fig. 52 and 54) at the height of the piezometer filters 5 and 6 we measured respectively 52.51% and 69,8% sand, 22,8% and 38.5% loam and 9.2% and 7.1% clay. The % clay are contradictory to what we perceived during the installation of piezometer 5 and 6, more clay was registered at the height of piezometer filter 5. The main soil texture in the vegetative buffer strip is sand. Clay will be the determining soil texture for the hydraulic conductivity as it fills up the little soil pores. Seelheim uses the d_{50} instead of Hazen which uses the d_{10}. The d_{10} is the most important soil fraction of the soil as most of the d_{10} particles will be clay. The d_{50} takes also loam into account which is not the determining soil textures for the soil within the vegetative buffer strip. As such, the formula of Hazen is best applicable to determine the hydraulic conductivity at the height of piezometer 5 and 6.

When installing piezometers there were some difficulties because soils where closing fast and it was difficult to install the piezometers. This could cause 'versmering' smearing of the soil and could have an influence on the hydraulic conductivity measured according to the rising-head method. A lower value could be measured.

According to formula of Hazen we expected also a lower hydraulic conductivity at the height of piezometer 6 due to the sandy clay layer at the height of the piezometer filter perceived during installation of the piezometer. But this is not the case. The d_{10} in piezometer 5 and 6 is respectively 4.3

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[3] GL= ground level

and 14.30. Clay is most present in piezometer 5. For piezometer 6 there is a little fraction of loam present in the d_{10} which causes the higher hydraulic conductivity.

Table 5: All 7 piezometers with different measured hydraulic conductivities

piezometer	**hydraulic conductivity**			**soil texture**
	rising-head method	*granulometry*		
	K (m/d) sludge test	*K (m/d) Hazen*	*K (m/d) Seelheim*	
1	0,09	no data	no data	sandy loam
2	0,25	no data	no data	sandy loam
3	0,05	no data	no data	loam
4	0,08	no data	no data	sandy clay
5	0,15	0,02	1,42	sandy loam
6	0,07	0,21	6,29	sandy clay
7	0,08	no data	no data	clay

Table 6: Summary hydraulic conductivity of different soil types (source: http://www.grondwaterformules.nl/index.php/vuistregels/ondergrond/doorlatendheid-per-grondsoort))

soil texture	**Hydraulic conductivity (m/day)**
heavy clay	0.0001
potting clay	0.001
moderatly heavy clay	0.01
sandy clay	0.05
boulder clay	0.05
peat	0.001-0.1
clayey peat	0.005
strong sandy peat	0.05
loam	0.05
sandy loam	0.3

8.4 Ammonium, nitrite and nitrate concentrations in groundwater

During the measuring period (May-October) piezometer 1 to 4 were measured five times and piezometer 5 and 6 two times. Piezometers 5 and 6were installed to verify and compare results obtained for piezometers 1 to 4 and to visualise a more correct groundwater flow. All results are exceeding the reference value for nitrate in groundwater (50mg/L) and for surface water category 2 (44mg/L) for all sampling moments, except for piezometer 4 and 6 at the border Barbierbeek / vegetative buffer strip. The legislative framework and this research focuses on nitrate, so only the results for nitrate will be plotted. A schematic representation of the results is given below with the exceedances with regard to the reference values indicated in red:

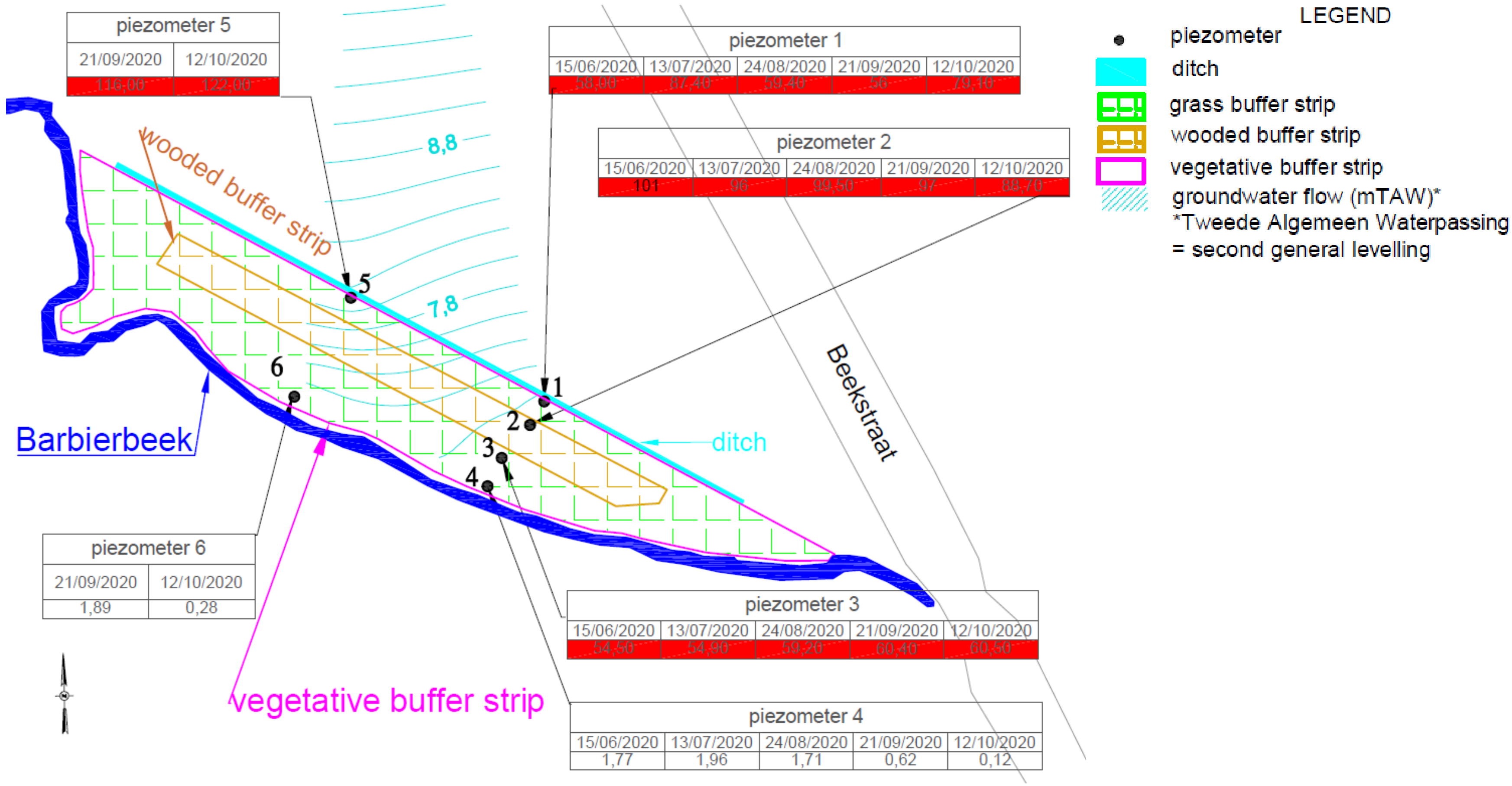

Fig. 39: schematic representation of the VBS, groundwater flow and all groundwater sampling results for nitrate. Results exceeding reference value of 50mg/l nitrate are indicated red.

Figure 40 plots nitrate concentrations per piezometer per sampling moment. The red dotted line indicates the reference value for groundwater (50mg NO_3^-/L). Piezometers 4 and 6 are not plotted as the concentration for nitrate in both piezometers for each sampling day are barely above the detection limit for nitrate (close to zero). Note: piezometers 5, 6 and 7 were only sampled during the two last sampling dates: 21/09/2020 and 12/10/2020.

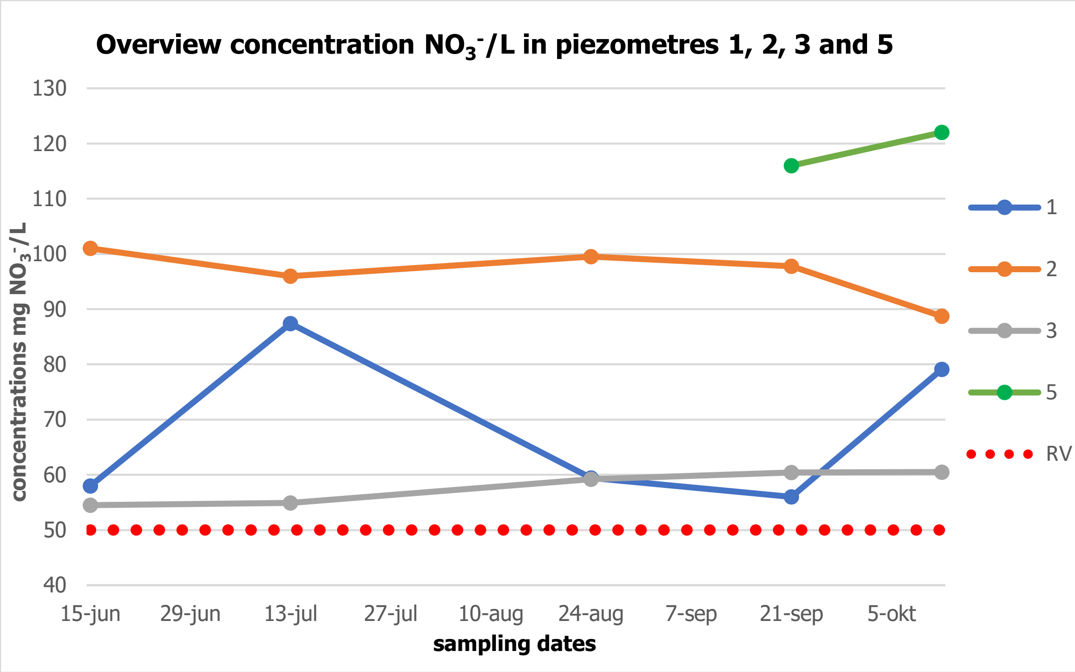

Fig. 40: Plotted results of the 5 sampling days for the parameter nitrate in groundwater for each piezometer[4]

Piezometer 5 and 6 are not plotted in figure 41 because there are only two results present.

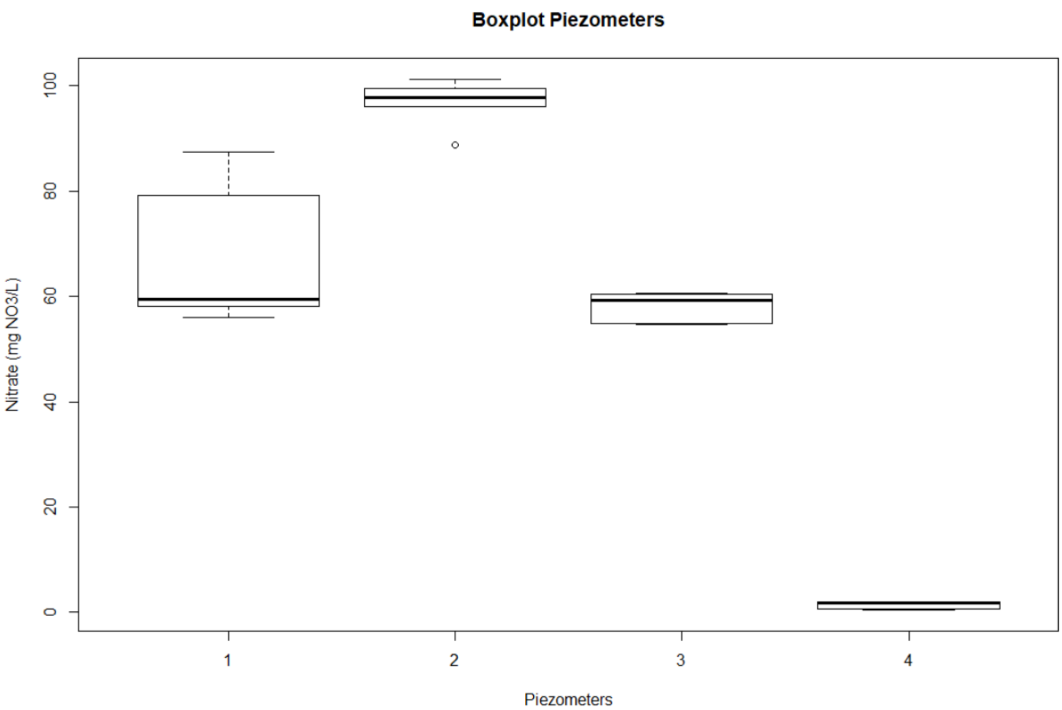

Fig. 41: boxplot for piezometer 1 to 4.

[4] See appendix x for graphs per piezometer for all sampling days and graphs drawn per sampling day for all sampled piezometers on that day.

Piezometer 5 close to the agricultural field show the highest concentrations of nitrate measured during the measuring period. Piezometer 1 also at the border with the agricultural field shows two higher values, sampling event two (13/07/2020) and five (12/10/2020). The increase on 12/10/2020 is possibly caused due to higher precipitation in the previous weeks (see attachment x) and because no further uptake of nutrients was possible due to the harvested maize on the agricultural field to the North of the VBS. Considering the low hydraulic conductivity it is normal that nitrate concentrations have not risen much, it takes time for nutrient rich water to reach piezometer 1 and 5 (inputs). Higher concentration of nitrate in all piezometers are expected in the following months after 12/10/2020. No specific explanation is present on today for the increase on 13 July 2020 for piezometer 1.

Fig. 40 is showing that the results of piezometers 3 and 4 do not fluctuate much during the measuring period. Piezometer 2 has one outlier according to figure 41, the concentration on the last sampling day was a bit lower then on previous sampling days. Piezometer 1 near the agricultural field has the biggest fluctuations over time, which could be attributed to the influx of nitrate from the agricultural field.

8.5 Mitigation capacity of the vegetative buffer strip

In chapter 7.5 it was hypothesized that the mitigation capacity of the VBS could be calculated as follows taking a presumed southern groundwater flow direction towards the Barbierbeek into account:

- The difference in nitrate concentration between piezometer 1 and 4;
- The difference in nitrate concentration between piezometer 5 and 6.

After determining the groundwater flow, this hypothesis cannot be followed as the groundwater flow deviates to a more westerly direction instead of a southern direction. Taking this into account the mitigation capacity of the VBS could be calculated as follows:

- The difference in nitrate concentration between piezometer 5 (input) and 6 (output);
- The difference in nitrate concentration between piezometer 5 (input) and 4 (output).

We measured a strong decline of nutrients between piezometer 5 (input) and 6 (output) plus 5 (input) and 4 (output). However on today the mitigation capacity of the VBS cannot be determined because there are too much variables which are not fully known: dilution of groundwater by surface water of the Barbierbeek, influence of sandy clay layer, quantitative amount of organic matter (important for denitrification), dissolved oxygen levels, influence of short period of measuring, seasonal variability in nutrient leaching…

Aforementioned uncertainties are further discussed in §9, discussion.

9. Discussion

Our study showed that nitrate concentrations varied between the different locations that were sampled along the Barbierbeek. Within the vegetative buffer strip and along the border with the agricultural field we measured nitrate concentrations that were higher than reference value for groundwater (50 mg/L) and surface waters category 2 (44 mg/L) (Emis Vito, 2021), which indicates the pressure from agriculture on ground and surface water. Along the border with the Barbierbeek and the vegetative buffer strip all sampling results for the parameter nitrate were lower than the reference values. It is not clear if there is direct effect of the vegetative buffer strip on the nitrate concentrations found in groundwater. Several factors could explain these observations.

Different processes within a vegetative buffer strip could attribute to the mitigation of nitrate leaching via shallow groundwater towards surface water: denitrification, vegetation uptake, microbial immobilization and dissimilatory nitrate reduction to ammonium (DNRA). **Denitrification and vegetation uptake** are considered the most important processes (Ballestrini et al., 2001; Gumiero et al. 2011 ; Hefting et al. 2006 ; Dhondt et al., 2006).

Different environmental regulators and factors are important for denitrification: oxygen availability, carbon availability, groundwater level, type of vegetation and soil textures. Oxygen availability and carbon availability are one of the most important environmental regulators for denitrification (Ballestrini et al., 2001; Gumiero et al. 2011 ; Hefting et al. 2006). Ballestrini et al. (2011) mentions the importance of other determining factor such as catchment hydrology, subsurface biochemistry and soil texture.
Oxygen availability could not be registered at every sampling point due to a bad influx of groundwater caused by a low hydraulic conductivity of the soil, the period and season of measuring plus the dry summer of 2020. The concentration of dissolved oxygen must be lower than <0,2 mg/l before denitrification can take place (Seitzinger et al. 2006). Several dissolved oxygen levels have been registered: piezometer 1 measures two out of two times more than 0,2mg/l, piezometer 2 measures 2,01 mg/l dissolved oxygen. No oxygen levels could be registered for piezometer 3, 4, 5 and 6. The measurements are too limited to draw definitive conclusions, but the preliminary results are showing that oxygen availability can be a limiting factor for denitrification within the vegetative buffer strip.

Carbon availability is important for heterotrophic denitrification (Korom 1992). Carbon serves as a reducer and uses nitrate as oxidizer (receiver of electrons). As groundwater levels were low (range between 0,98-2,48 m-GL) during our measurement period (May-October) we can assume that groundwater levels were located in soil layers where possibly little organic material was present that could serve as reducer within the dentification process (Gumiero et al. 2011). Although during winter groundwater levels will rise, possibly leading to more carbon available for the denitrification process. Carbon availability can be a limiting factor for the denitrification process within the vegetative buffer strip as groundwater levels are levelling soil layers where little or no available organic matter is present. Although nitrate can also be reduced by reduced pyrite (FeS_2) or manganese carbonate ($MnCO_3$) (autotroph denitrification) or dissimilarly nitrate reduction (Korom 1992 ; Hefting et al. 2006). In most studies heterotrophic denitrification is held as the most important process. However Korom (1992) mentions that if Mn^{2+}, Fe^{2+} and HS^- are present in large quantities they can participate in the denitrification reactions.

Hefting et al. (2006) mentions the predominate role of soil textures heterogeneity flow patterns and residence time. Also Williams et al. (2014) also mentions the importance of knowing the flow patterns. He stipulates the shallow groundwater dynamics, as they play a critical role in determining the chemistry and movement of nitrogen in a riparian zone, vegetative buffer strip. Near the research location different groundwater flow patterns were registered: at the border of the agricultural field and the vegetative buffer strip the groundwater flow has a southern direction, further away from this border the groundwater flow deviates to a south-eastern direction.

Hefting et al. (2006) and Williams et al. (2014) are mentioning residence time as another important factor which affects nitrogen behaviour. Residence time is important in the denitrification process for nitrate in groundwater. The longer nitrate rich groundwater is present within the vegetative buffer strip before entering the surface water of the Barbierbeek the more denitrification can take place. The residence time is affected by the different soil textures. In the vegetative buffer strip different soil textures were registered: sandy loam, loam and sandy clay. The residence time is measured by determining the hydraulic conductivity, the speed at which free water flows through the soil matrix. The determined hydraulic conductivities vary between 0,05-0,25 meter/day.

An explicit lower conductivity or a higher clay amount at the height of the border Barbierbeek with the vegetative could have explained the lower nitrate concentrations due to a higher residence time and more time for denitrification to take place. But we registered less clay near the border Barbierbeek /vegetative buffer strip (piezometer 6) than the border agricultural area/vegetative buffer strip (piezometer 5). Although during piezometer installation we perceived more clay at the height of piezometer 6. Low hydraulic conductivities have been determined along the Barbierbeek (sandy clay layer). Low hydraulic conductivities have also been determined in other places within the vegetative buffer strip. Considering the soil textures determined during piezometer installation and the known theoretic hydraulic conductivity for each soil texture the results obtained by applying the rising-head method and the granulometry method according to the formula of Hazen are considered reliable for the vegetative buffer strip. The results obtained by adapting granulometry according to the formula of Seelheim are not conclusive. The obtained results are far from the theoretical values according to different soil textures. The main soil texture in the vegetative buffer strip is sand. Clay will be the most determining soil texture for the hydraulic conductivity as it fills up the soil pores. Seelheim uses the d_{50} instead of Hazen which uses the d_{10}. The d_{10} is the most important soil fraction of the soil matrix as most of the d_{10} particles will be clay. The d_{50} takes also loam into account which is less determining for the hydraulic conductivity. As such, the formula of Hazen is best applicable to determine the hydraulic conductivity at the height of piezometer 5 and 6.

Dilution of groundwater with surface water of the Barbierbeek can also play an important role as noticeably higher groundwater levels were registered in all piezometers between the penultimate and last sampling day due to a much higher water column registered in the Barbierbeek due to heavy precipitation between the penultimate and last sampling day. In piezometer 4 and 6 groundwater levels rose with a factor 1,57 compared to those in piezometers 1, 2, 3 and 5.

Next to the denitrification, uptake of nutrients by vegetation can be an important process within a riparian zone or vegetative buffer strip to mitigate nutrient leaching towards surface water (Ballestrini et al., 2001; Gumiero et al. 2011 ; Hefting et al. 2006) . Groundwater level and root depth are important factors in case of nutrient uptake by vegetation (Søvik and Syversen, 2008 ; Ballestrini et al. 2011). During the measuring period (May-October) the lower groundwater levels caused by drought were hampering the vegetation to take up nutrients out of groundwater. The wooded strip is more deeply rooted, we estimate that its rooted to a depth of 1m below ground level, most of the time still higher than the groundwater levels registered during the measuring period in piezometer 3 and 4 at the borders of the wooded buffer zone (range groundwater level 0,98-2,31 m-GL). As the research location is situated in a temperate climate it is important to consider the seasonal variability in nutrient uptake by plants (Dhondt et al. 2006). During winter time nutrient uptake by plants is limited, denitrification is assumed to be the main process of nitrate removal (Haycock and Pinay, 1993; Jack et al. 1994). Although the denitrification potential decreases when soil temperature is lower than 5°C (Focht and Verstraete, 1977; Ryden, 1983; Webster and Goulding, 1989).

Next to the importance of oxygen availability, carbon availability, soil textures (residence time), groundwater level... The width of a buffer strip can be important. The wider the strip the more time there is for denitrification and the more vegetation is able to take up nutrients. In the scientific literature there is no consensus as to which width a vegetative buffer strip is the most efficient in nitrogen mitigation towards surface water, which is evident as we consider the previous mentioned variables. Schmitt et al. (1999) recommends 15m as most effective width, Lind et al. (2019) concludes that a 3m width buffer strip acts as a basic nutrient filter and Gumiero et al. (2011) concludes that a 15m width buffer strip can remove an excess of nitrate if concentrations are lower than 22 mg/l. Gumiero et al. (2011) describes narrower buffer strips as likely adequate. Not every research recommends a specific width, Valkama et al. (2019) concludes that there is no impact of the width on the mitigation capacity.

The width of a vegetative buffer strip in a riparian zone depends on the goal (nutrient removal, stimulating biodiversity, bird diversity…) and the situation on site: geology, nutrient concentration, plant species in vegetative buffer strip, groundwater level, temperature, available electron donors, organic matter… The extent to which width a vegetative buffer strip plays a role in the mitigation of nutrient leaching must be determined site by site.

Different vegetations types are present within the vegetative buffer strip with possible different mitigation capacities. Piezometers 2 and 3 could serve as references for the mitigating capacity of the wooded buffer strip within the vegetative buffer strip. However considering the groundwater flow, this assumption cannot be fully confirmed as the groundwater flow at the level of piezometer 2 and 3 is almost equal to the direction of the wooded buffer strip zone (western direction). If groundwater flow was perpendicular to the direction of the wooded buffer zone, piezometer 2 and 3 can serve as references. The same story can be build up for the gras buffer strip. The difference between piezometer 1 and 2 plus 3 and 4 could count as the mitigation capacity for the gras buffer strips. Although considering the groundwater flow this statement is incorrect, the results would be indicative.

At the start of this study we hypothesized that piezometer 1 and 4 (installed in the first phase of piezometer installations dd. 15/05/2020) served as reference for input (piezometer 1) and as output (piezometer 4). Considering the determined groundwater flow piezometer 1 and 4 do not longer serve completely as input and output references near the vegetative buffer strip. More correct would be that piezometer 1 and 5 serves as input and piezometer 4 and 6 as outputs.

Groundwater levels do not only affect the denitrification process and nutrient uptake by plants but also another research location specific factor, the Northern ditch: when the groundwater rises into the ditch to the North of the vegetative buffer strip, a part of the nutrient rich groundwater may be discharged via this ditch into the surface water of the Barbierbeek. A part of the mitigating capacity of the vegetative buffer strip is nullified if a part of the groundwater is diverted via the ditch instead of passing through the vegetative buffer strip. If so piezometers 1 and 5 do not longer serve as actual input for the vegetative buffer strip.

Not only groundwater is discharged via the ditch but also run-off water. During the first visit at the research location dd. 07/02/2020, there was a direct run-off registered near the vegetative buffer strip (attachment 9). The water from the agricultural field North of the vegetative buffer strip is captured into a ditch. The ditch runs almost directly into the Barbierbeek. The run-off water had organoleptic signs (colour) of being polluted with nutrients. The intention was to sample the run-off to determine to what extent the run-off water contributes to the nutrient load of the Barbierbeek. However, there was no run-off water registered during the research period (May-October) due to very dry conditions. Run-off is less present during summer months, because plants absorb water, plants retain water physically, evaporation is higher due to higher temperatures and water infiltrates in the ground. Run-off will probably only take place in the late fall, winter and early spring (November-March).

There are two options to avoid nutrient rich run-off water directly feeding the Barbierbeek. Option one, filling up the ditch with soil or removing the direct connection to the Barbierbeek: run-off will no longer pass via the ditch into the surface water of the Barbierbeek but it will flow over the vegetative buffer strip and infiltrate into the soil of the vegetative buffer strip. Possibly nutrient rich run-off water can be taken up by plants (or infiltrate into the soil and can be degraded by bacterial activity, denitrification). For nitrate marginal gains will be achieved, in case of phosphorus more positive effects will be achieved (personal communication Professor De Neve). Filling up the ditch would also stimulate sediment capturing (erosion) from agricultural field (Cole et al., 2020).

A second option could be to install wetlands at the both ends of the ditch. Wetlands can function as nature-based solutions to mitigate nutrient leaching via the ditch into the surface water of the Barbierbeek (Donoso et al. 2017). However, it must be investigated whether these wetlands can be implemented spatially and technically. Wetlands can contribute together with the vegetative buffer strip to a more biodiverse ecosystem and to carbon sequestration (Moreno-Mateos et al. 2012).

Vegetative buffer strip do have a wide range of other ecosystem functions (regulating, support and cultural services) next to the mitigation capacity. An important regulating function is climate regulation. Photosynthesis is one of the major systems of carbon capturing. The existing grass buffer strip and wooded buffer zone engage photosynthesis (primary production) (Cole et al., 2020). According to Guo and Gifford (2001) a transition of crop towards wood or pasture delivers respectively 53% and 19% more carbon sequestration. Although most of the studies used in the meta-analysis are in different climatological circumstances, other studies do confirm that a transition from agriculture to a forested/wooded area or a grassland is better in case of carbon sequestration (Post and Kwon, 2008 ; Schulp et al. 2008). The transition of land use, agricultural field to a vegetative buffer strip, North of the Barbierbeek could deliver more carbon sequestration.

The vegetative buffer strip has also supportive services: nutrient cycle (discussed in §3) and primary production by autotrophic organisms (plants). The walking path/grass buffer strip along the Barbierbeek fulfils a cultural ecosystem service.

Besides ecosystem functions the vegetative buffer strip fulfils other services to, for example stimulating biodiversity (Cole et al., 2020). Agricultural land is monotonous in terms of biodiversity. Change in land use form agricultural land to a vegetative buffer strip increases biodiversity. Although it is important to have a mix of different kind of buffer strips in a riparian buffer strip. A combination of a wooded strip with a grass buffer strip will stimulate biodiversity more than only a buffer strip and vice versa (Cole et al., 2020). Also river banks are more stabled as they are in use for vegetative buffer strips because there is less heavy transport (agricultural machinery) on the field and roots of plants can promote stability, they are not harvested as regularly as on an agricultural field (Cole et al., 2020). A vegetative buffer strip prevents also farmers to use fertilizers and spray materials near the surface water, which has a positive effect on the chemical and ecological water quality of the surface water.

Different scientific literature prove the effectiveness of a vegetative buffer strip. For example Balestrini et al. (2011) mentions that he measured high mean concentrations at the exit of crop fields near the surface water (10-90 mg/L^{-1} $N\text{-}NO_3^-$). But nitrate levels within the riparian sites were very low. The width of the buffer strips were differing between 5 and 15m. Gumiero et al. (2011) mentions high removal rates (63-64%) already after the first year and a further increase in the second and third year, the highest rates were registered in summer and autumn. The riparian site is 227m long and 30m wide. Hefting et al. (2006) registered 63% removal in the grassland zone and 38% removal of the incoming nitrate load in a forested zone. Dhondt et al. (2006) registered a 92-100% removal efficiency in a mixed and grass riparian site, the forested riparian zone removed 72-90%. Both zones were 30m wide.

After interpretation of the sampling results near the vegetative buffer strip along the Barbierbeek we observed a small increase of nitrates in the piezometers serving as input references (piezometer 1 and 4) between the fourth (21/09/2020) and fifth sampling event (12/10/2020) possibly due to higher precipitation in the previous weeks and no further uptake of nutrients was possible due to the harvested maize to the North of the vegetative buffer strip. Balestrini et al. (2011) also registered a higher concentration of nitrate due to very intense or prolonged rainy events. Considering the low hydraulic conductivity it is normal that nitrate concentrations have not risen much, it takes time for nutrient rich water to reach piezometer 1 and 5 (inputs). Higher concentration of nitrate are possibly expected in the following months after 12/10/2020 (fall and winter period).

There is a low variability of nitrate concentrations in one and the same piezometers between different sampling events but differences have been measured between different piezometers which can possibly indicate the mitigation capacity of the vegetative buffer strip. The period of measuring was too short, variables which determine denitrification and vegetation uptake are not fully known and there are too much uncertainties about different general variables regarding the vegetative buffer strip to draw a definitive conclusion about the mitigation capacity of the vegetative buffer strip. Further measuring for at least an entire year is required because most of the nutrient leaching will occur in fall, winter and early spring. Because plants are no longer present on the agricultural field and are not able to take up nutrients, precipitation is higher during these periods of time and evaporation is less higher which results in a net higher volume of water which can infiltrate into the soil and possibly causes nutrient leaching. Since the study took place between April and October there were no measurements of winter available.

10. Conclusion

We found that the groundwater levels exceed the norm for nitrate at most locations. A five month measurement campaign showed that the concentrations of nitrate in groundwater exceed the reference value (50mg/l) for nitrate in groundwater and the reference value for river watercourses category two (44mg/L) in five out of seven piezometers on all five sampling events. No clear explanation can be given on today why the other two piezometers do not exceed the reference values, these piezometers are installed near the border Barbierbeek and vegetative buffer strip.

There is a low variability of nitrate concentrations in some piezometers between different sampling events but differences have been measured between different piezometers. Considering these differences and the results of aforementioned studies (§9, discussion), we conclude that the vegetative buffer strip can possibly be an nature-based solution in land management to mitigate nutrient leaching (diffuse pollution) via groundwater towards the surface water of the Barbierbeek. As such, the vegetative buffer strip along the Barbierbeek can possibly contribute to reach the goals set by the United Nations (SDG 6 and 15) and Water-Land-Schap project Barbierbeek Verbindt! (improving water quality).

A definitive conclusion on the mitigating capacity of the vegetative buffer strip near the Barbierbeek cannot be made since it was only measured during May-October. This short period of sampling excludes several determining factors that possibly influence the mitigating capacity of the vegetative buffer strip near the Barbierbeek. Also several uncertainties should be further investigated to determine to what extent the vegetative buffer strip near the Barbierbeek contributes to mitigation of nutrient leaching via ground to surface water.

Next to the possible mitigation capacity the vegetative buffer strip has several ecosystem services (regulating, supportive and cultural) and can be used as a nature connecting area in the context of current fore-mentioned policy objectives. However a vegetative buffer strip cannot be created without any further research and without consulting local stakeholders. The success of this nature-based land management solutions is depending on the social support base. Farmers, which are one of the most important stakeholders, should be aware of the potential benefits of a vegetative buffer strip. Informing is knowing. Common knowledge is the basis of a good cooperation.

Actions are needed. A press release of the VLM (attachment 11) confirms that the overall surface water quality in case of nitrate is getting worse the last three years, due to dry and hot springs and summers. If further research near the current research location confirms that a vegetative buffer strip is able to mitigate diffuse pollution from an intensively used agriculture area near a lowland stream in Belgium, scaling up this project towards other watercourses with similar problems could be done at a small scale, case by case. However the effectiveness of future possible vegetative buffer strip should not be studied endlessly. Dhondt et al. (2006) confirmed already the mitigation capacity of different types of vegetative buffer strips in a riparian zone along lowland streams in Belgium. A pragmatic approach, with the synergy between agriculture and the environment, should be put forward to achieve a good chemical and ecological state of the surface water in the Barbierbeek and other water river systems.

11. Recommendations

Many opportunities near the vegetative buffer strip are present and could be elaborated. Recommendations are made for further fieldwork, run-off catchment, maintenance of the vegetative buffer strip and general recommendations.

11.1 Fieldwork

The sampling period must be continued for at least one year (until 15/06/2021). During the fieldwork several other field observations/measurement should be made:

- Dissolved oxygen concentration and oxidation reduction potential has to be registered on all piezometers to further analyse the bacterial activity (denitrification) in the with water saturated soil zone in order to determine the contribution of bacterial degradation activity (denitrification) to the mitigation capacity of the vegetative buffer strip.
- At different heights within the vegetative buffer strip the amount of organic matter should be measured to determine if organic matter can contribute to heterotrophic denitrification process.
- The possible interaction between the surface water of the Barbierbeek and the groundwater of the vegetative buffer strip must be evaluate. When this exercise is carried out, special attention should be given to piezometer 3 especially for groundwater levels, nitrate concentrations and the changing water column heights in Barbierbeek. Because piezometer 3 is the closest towards the Barbierbeek besides piezometer 4 and 6. This is important to determine the possible sphere of influence of the surface water on the groundwater levels and nitrate concentrations in the vegetative buffer strip.

Additionally, communication with the owner or farmer of the agricultural land to the North of the vegetative buffer strip should be started as piezometers should be installed on his land. This piezometer has to act as a reference for the nitrate concentrations in groundwater in the agricultural area. It is recommended to install at least two piezometers so that results can be validated among each other and spatial variability in nitrate concentrations can be possibly registered and taken into account as much as possible.

11.2 Run-off

During our visit 07/02/2020 we perceived run-off water feeding directly the Barbierbeek via the ditch to the North of the vegetative buffer strip (see attachment 9).

- Sampling of the run-off water should be done at the ends of the ditch (run-off points, see attachment 9). If no water is present, it must be sampled during heavy rainfall, because there is bigger chance of water being present in the ditch during heavy rainfall. It is useful for further interpretation of the possible nutrient load via run-off towards the Barbierbeek.
- If water is present into the ditch the groundwater level in piezometer 1 and 5 should be compared with the height of the ditch to evaluate if any groundwater is present in the ditch.
- If there is run-off present it should be analysed on ammonium, nitrite and nitrate. Run-off water contains relatively more phosphorus than nitrate, phosphorus should be added to the analyses (personal communication professor De Neve).

In addition several solutions are presented to avoid run-of water ending up directly into the Barbierbeek:

- Filling up the ditch with soil.
- Installing wetlands at both ends of the ditch. This option seems the least obvious today as a wetland requires constant feed of nutrient rich ground or run-off water, which is not the case

as the ditch is occasionally dry. Even with taking into account the benefits of a wetland (carbon sequestration, stimulating biodiversity…), the option to fill up the ditch seems to be better. Filing up the ditch is the least labour intensive, least maintenance sensitive, most sustainable in the future and most easy solution to execute.

During the visit on 07/02/2020 we perceived several other 'direct feeding points' of run-off water with possible nutrient rich water along the Barbierbeek. Further investigation is strongly recommended.

11.3 Maintenance

Biomass (grass and wood buffer strip) must be removed on a regular basis in order to guarantee the effectiveness (absorption of nutrients) of the vegetative buffer strip and to prevent nutrient saturation, otherwise a vegetative buffer strip can act as a source of nutrients. (Lorna et al. 2020, Cole et al. 2020, Hefting et al. 2006, personal communication Professor De Neve). Lorna et al. (2020) mentions that removal of biomass should be carefully managed to avoid or reduce impacts on the water quality and biodiversity.

11.4 General

It is recommended to plant more threes within the vegetative buffer strip. They are more deeply rooted and supply available carbon in deeper soil layers which benefits denitrification and nutrient uptake (Hefting et al. 2006).

Before constructing a vegetative buffer strip every research location/stream must be investigated separately due to high geohydrological, spatial difference and site specific differences which affect the mitigation capacity of a vegetative buffer strip. Not every 'meter' of a river bank along a stream must be investigated. When the geohydrological characteristics are more or less the same a small scale research can be upscaled to a larger area along the same stream. A pragmatic approach should be put forward.

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13 Attachments

Attachment 1: Laboratory reports

<u>ammonium, nitrite and nitrate</u>

granulometry

Attachment 2: Example tables for determination hydraulic conductivity according to rising-head method and granulometry

Table 7: Fill-in sheet sludge test

time (minutes)	groundwater level (m-GL[5])
0.5	
0.75	
1	
2	
3	
5	
8	
12	
16	
20	
24	

Table 8: Rising-head non intersecting piezometers

Parameter	Value	Unit
piezometer	1	
pump duration	1	min
pumped volume (V)	2	l
pump flow (Q)	2.88	m³/d
level at rest (h0)	2.64	m
filter depth bottom	4.13	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.03	-
t37	14.39327586	min
K	6.50419E-05	m/min
K	**0.093660369**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.64	0	-	-	
4.13	1	0,00	1	0
4.08	1.5	0,5	0.966443	-0.0148238
4.06	1.75	0,75	0.9530201	-0.0208979
4.04	2	1	0.9395973	-0.0270582
3.96	3	2	0.885906	-0.0526123
3.88	4	3	0.8322148	-0.0797646
3.75	6	5	0.7449664	-0.1278633
3.57	9	8	0.6241611	-0.2047033
3.35	13	12	0.4765101	-0.3219279
3.16	17	16	0.3489933	-0.4571829
3	21	20	0.2416107	-0.6168838
2.9	25	24	0.1744966	-0.7582129
				-0.4317983

[5] meters minus groundwater level

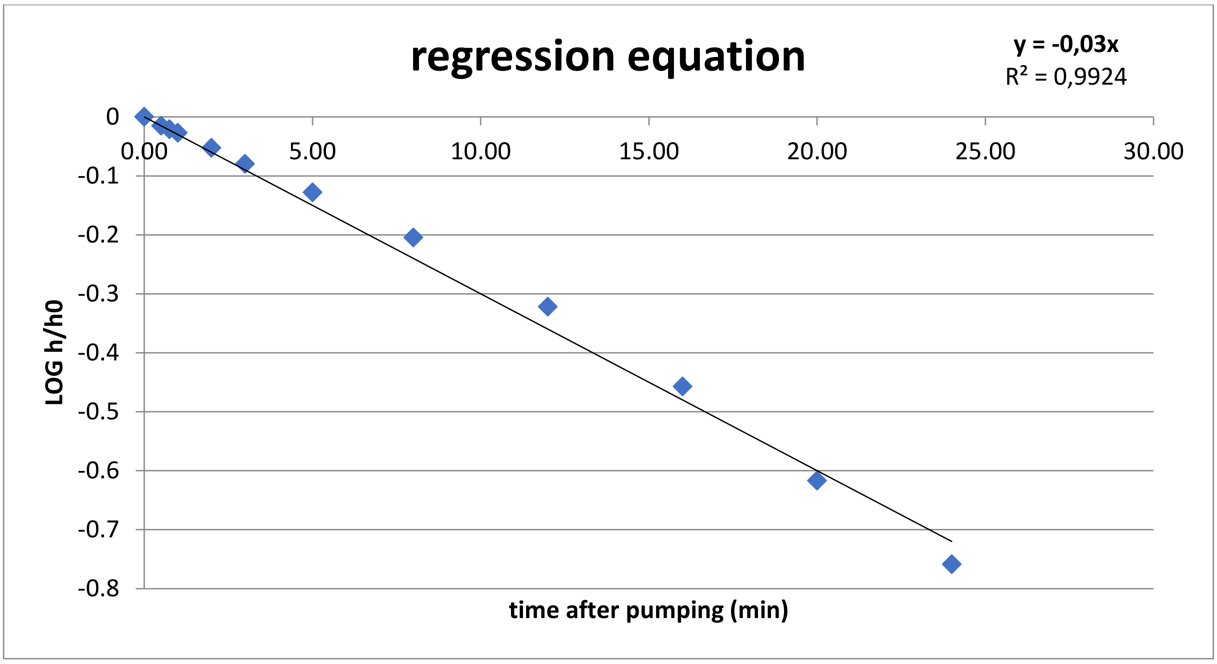

Fig. 42: Fig. example to calculate the rico

diameter < at X µm	accumulated fraction	piezometer number	5
	% m/m ms	depth	200-300
		Textural triangle	
2000	99,91	sand	52,21
1000	99,9		
500	99,7		
250	97,9		
125	76,6		
63	47,7	loam	38,5
50	40,5		
45	37,9		
16	14		
2	9,2	clay	9,2
d_{10}	4,333333333		
d_{50}	67,93425606		

		K m/s	K m/d
Hazen	$K = 0{,}0116\, d_{10}^2$	**2,18E-07**	**0,02**
Seelheim	$K = 0{,}003557 d_{50}^2$	**1,65E-05**	**1,42**

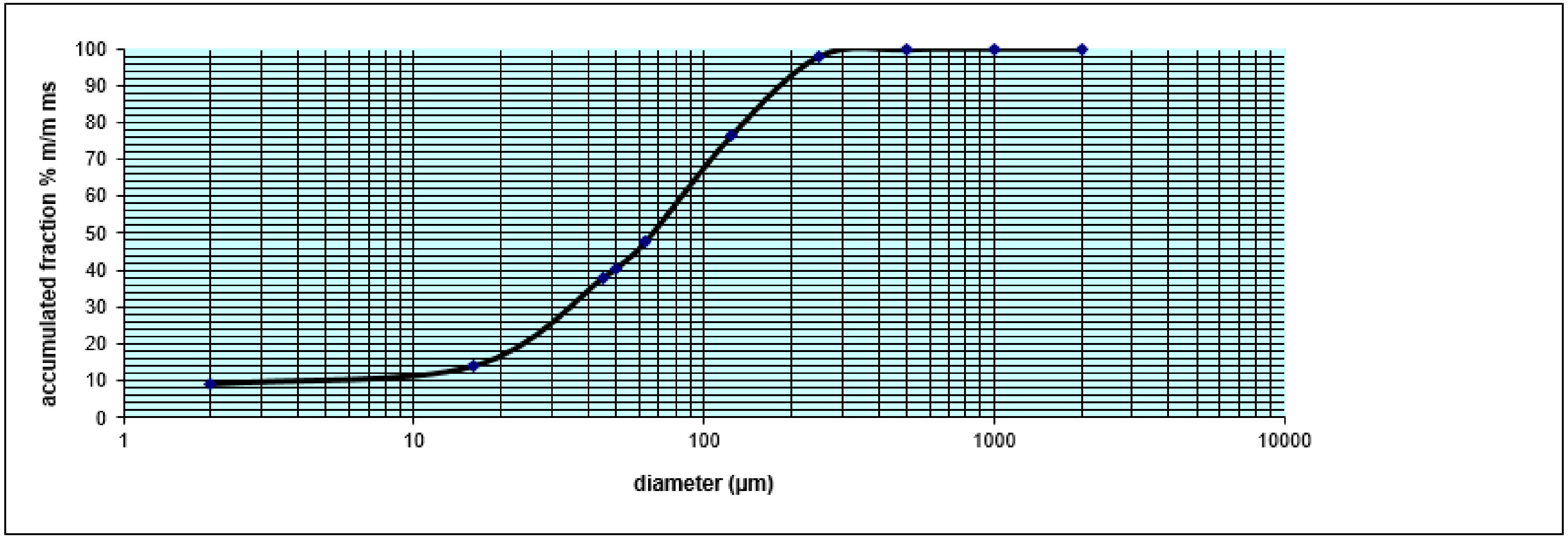

Fig. 43: Spreadsheet to calculate the hydraulic conductivity by Hazen and Seelheim by using grain size distributions (granulometry) (source: Universoil BV).

To do a textural analysis the textural triangle can be used:

% SAND % CLAY
64,7 11

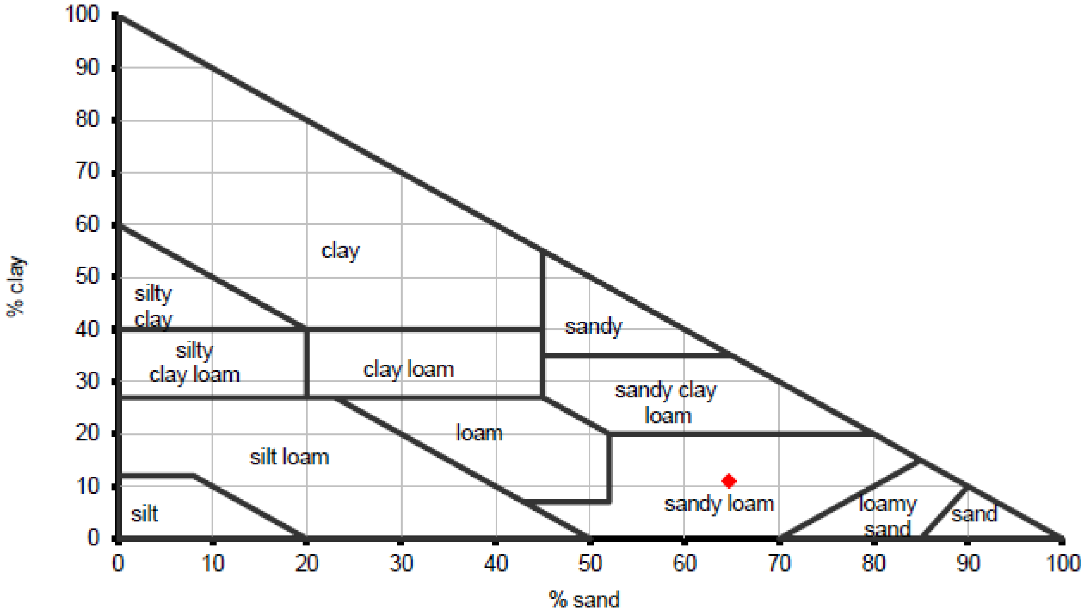

Fig. 44: Plot results of textural analysis on textural triangle (Source: Gerakis and Bear 2000)

To use this textural triangle the % sand and clay have to be filled in the excel spreadsheet. The red dot that appears in the texture triangle indicates which texture class the soil belongs to.

Results of the rising-head method, granulometry test and the textural triangle have to be interpreted. These tests have their limitations, it is strongly recommended to compare the results with the drilling description as mentioned before, after comparing results interpretation of the results must be made.

Attachment 3: Raw data + calculations hydraulic conductivity

Rising-head method

Table 9: Sludge test piezometer 1

Time (minutes)	Groundwater level (m-GL[6])
0.5	4.08
0.75	4.06
1	4.04
2	3.96
3	3.88
5	3.75
8	3.57
12	3.35
16	3.16
20	3.0
24	2.9

Parameter	Value	Unit
piezometer	1	
pump duration	1	min
pumped volume (V)	2	l
pump flow (Q)	2.88	m³/d
level at rest (h0)	2.64	m
filter depth bottom	4.13	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.03	-
t37	14.39327586	min
K	6.50419E-05	m/min
K	**0.093660369**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.64	0	-	-	
4.13	1	0.00	1	0
4.08	1.5	0.5	0.966443	-0.0148238
4.06	1.75	0.75	0.9530201	-0.0208979
4.04	2	1	0.9395973	-0.0270582
3.96	3	2	0.885906	-0.0526123
3.88	4	3	0.8322148	-0.0797646
3.75	6	5	0.7449664	-0.1278633
3.57	9	8	0.6241611	-0.2047033
3.35	13	12	0.4765101	-0.3219279
3.16	17	16	0.3489933	-0.4571829
3	21	20	0.2416107	-0.6168838
2.9	25	24	0.1744966	-0.7582129
				-0.4317983

[6] Meters minus groundlevel

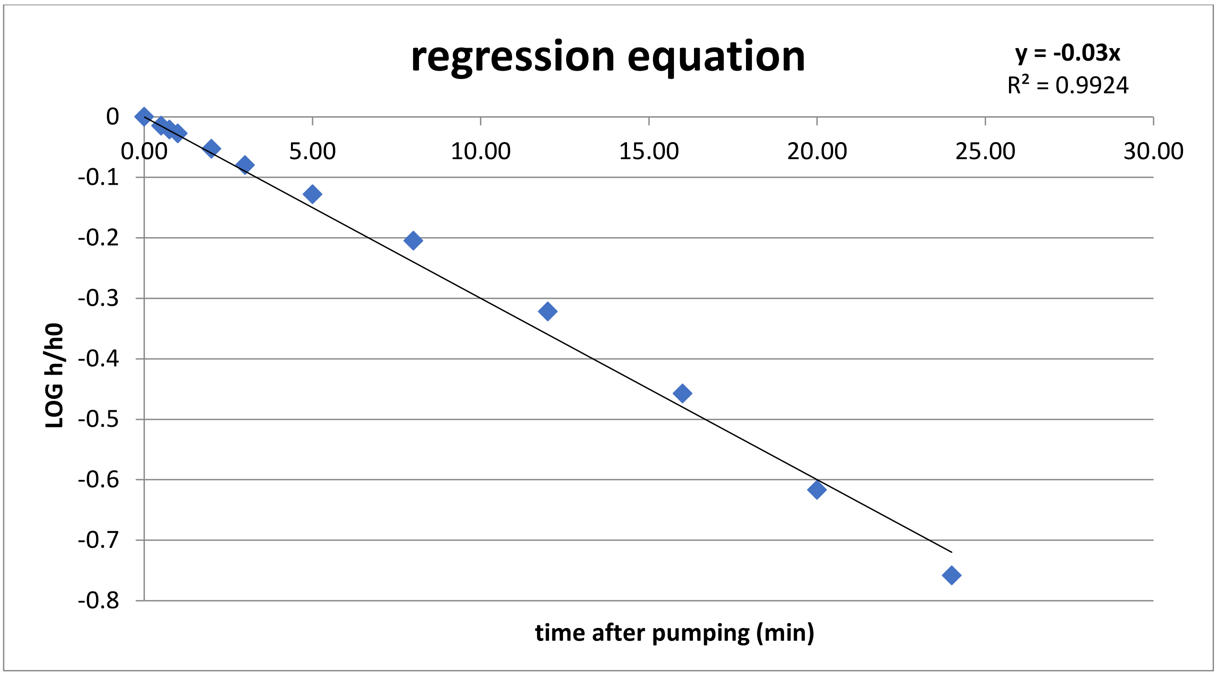

Fig. 45: Regression equation for sludge test piezometer 1

Table 10: Sludge test piezometer 2

Time (minutes)	**Groundwater level (m-GL)**
0.5	3.89
0.75	3.84
1	3.8
2	3.62
3	3.48
5	3.14
8	2.77
12	2.68
16	2.62
20	2.6
24	2.58

Parameter	Value	Unit
piezometer	1	
pump duration	1.5	min
pumped volume (V)	2	l
pump flow (Q)	1.92	m³/d
level at rest (h0)	2.56	m
filter depth bottom	4.05	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.0823	-
t37	5.246637618	min
K	0.000178432	m/min
K	**0.256941611**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.56	0	-	-	
4.05	1.5	0.00	1	0
3.89	2	0.5	0.8926174	-0.0493346
3.84	2.25	0.75	0.8590604	-0.0659763
3.8	2.5	1	0.8322148	-0.0797646
3.62	3.5	2	0.7114094	-0.1478804
3.48	4.5	3	0.6174497	-0.2093984
3.14	6.5	5	0.3892617	-0.4097583
2.77	9.5	8	0.1409396	-0.850967
2.68	13.5	12	0.0805369	-1.094005
2.62	17.5	16	0.0402685	-1.395035
2.6	21.5	20	0.0268456	-1.5711263
2.58	25.5	24	0.0134228	-1.8721563
				-0.4317983

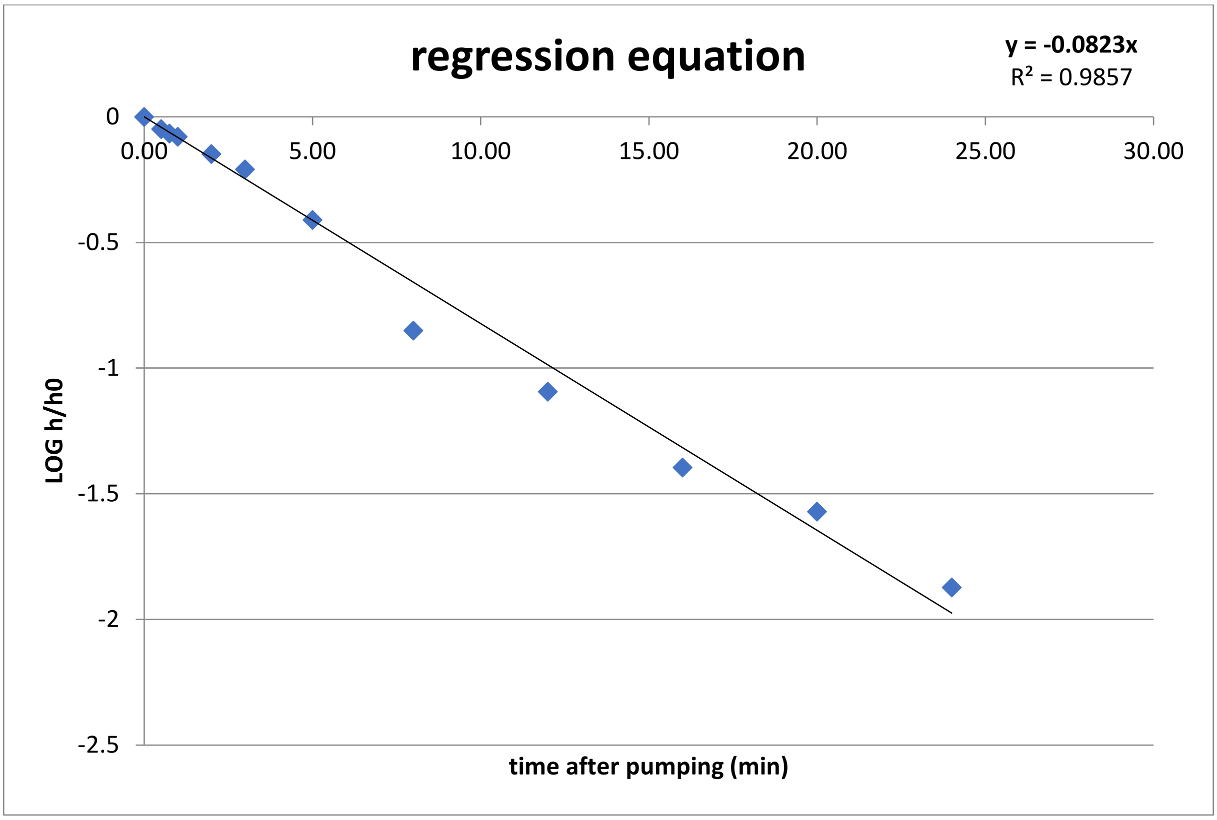

Fig. 46: Regression equation for sludge test piezometer 2

Table 11: Sludge test piezometer 3

Time (minutes)	**Groundwater level (m-GL)**
0.5	4.00
0.75	4.00
1	4.00
2	3.98
3	3.97
5	3.96
8	3.94
12	3.9
16	3.87
20	3.85
24	3.82

Parameter	Value	Unit
piezometer	3	
pump duration	1.5	min
pumped volume (V)	2.5	l
pump flow (Q)	2.40	m³/d
level at rest (h0)	2.18	m
filter depth bottom	4	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.019	-
t37	22.72622505	min
K	4.11932E-05	m/min
K	**0.059318233**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.18	0	-	-	
4	1.5	0.00	1	0
4	2	0.5	1	0
4	2.25	0.75	1	0
4	2.5	1	1	0
3.98	3.5	2	0.989011	-0.0047989
3.97	4.5	3	0.9835165	-0.0072184
3.96	6.5	5	0.978022	-0.0096514
3.94	9.5	8	0.967033	-0.0145587
3.9	13.5	12	0.9450549	-0.0245429
3.87	17.5	16	0.9285714	-0.0321847
3.85	21.5	20	0.9175824	-0.0373549
3.82	25.5	24	0.9010989	-0.0452275
				-0.4317983

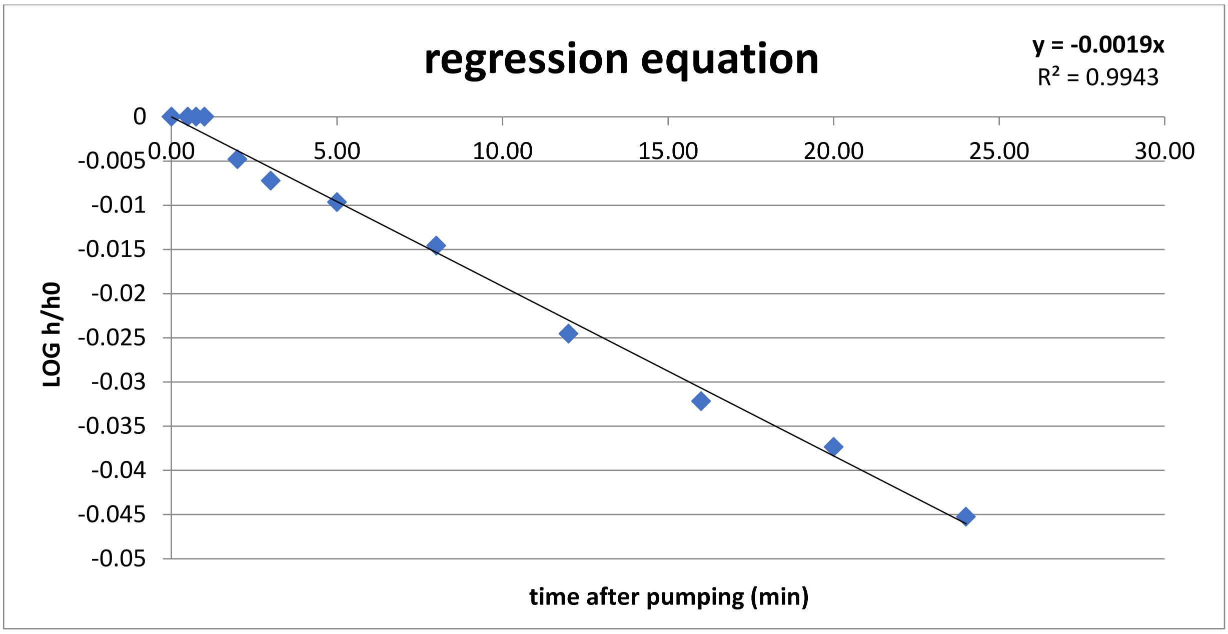

Fig. 47: Regression equation for sludge test piezometer 3

Table 12: Sludge test piezometer 4

Time (minutes)	Groundwater level (m-GL)
0.5	4.06
0.75	4.06
1	4.04
2	4.02
3	3.99
5	3.97
8	3.94
12	3.88
16	3.83
20	3.78
24	3.73

Parameter	Value	Unit
piezometer	1	
pump duration	1.5	min
pumped volume (V)	3	l
pump flow (Q)	2.88	m^3/d
level at rest (h0)	1.53	m
filter depth bottom	4.06	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.026	-
t37	16.607626	min
K	5.63697E-05	m/min
K	**0.081172319**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
1.53	0	-	-	
4.06	1.5	0.00	1	0
4.06	2	0.5	1	0
4.06	2.25	0.75	1	0
4.04	2.5	1	0.9920949	-0.0034468
4.02	3.5	2	0.9841897	-0.0069212
3.99	4.5	3	0.972332	-0.0121854
3.97	6.5	5	0.9644269	-0.0157307
3.94	9.5	8	0.9525692	-0.0211035
3.88	13.5	12	0.9288538	-0.0320527
3.83	17.5	16	0.9090909	-0.0413927
3.78	21.5	20	0.8893281	-0.050938
3.73	25.5	24	0.8695652	-0.0606978
				-0.4317983

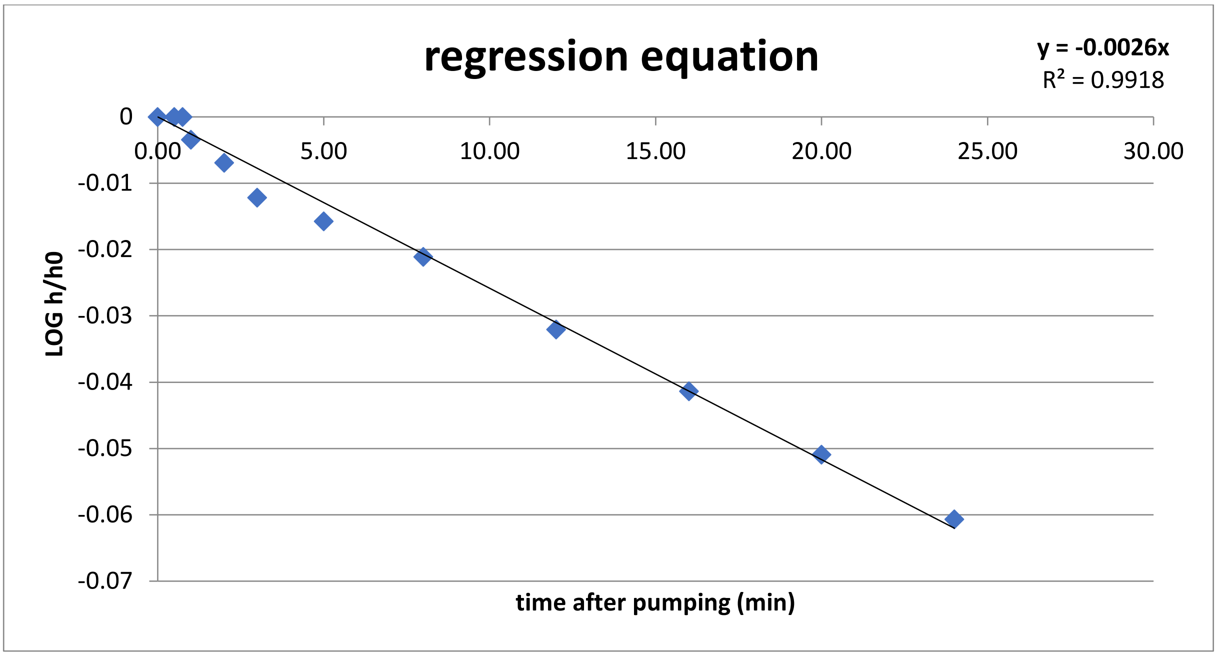

Fig. 48: Regression equation for sludge test piezometer 4

Table 13: Sludge test piezometer 5

Time (minutes)	**Groundwater level (m-GL)**
0.5	3.95
0.75	3.92
1	3.86
2	3.71
3	2.56
5	3.27
8	3.17
12	3.06
16	3.0
20	2.93
24	2.89

Parameter	Value	Unit
peilput	1	
pompduur	1.5	min
opgepompt volume (V)	3	l
pompdebiet (Q)	2.88	m³/d
peil in rust (h0)	2.78	m
filterdiepte (onderkant)	4.06	m
lengte van filter (Le)	1	m
r (m) (binnenstraal peilbuis)	0.025	m
R (m) (straal boorgat)	0.05	m
a (af te lezen uit regressievergelijking)	-0.0484	-
t37	8.921451982	min
K	0.000104934	m/min
K	**0.151105395**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.78	0	-	-	
4.06	1.5	0.00	1	0
3.95	2	0.5	0.9140625	-0.0390241
3.92	2.25	0.75	0.890625	-0.0503051
3.86	2.5	1	0.84375	-0.0737862
3.71	3.5	2	0.7265625	-0.138727
3.56	4.5	3	0.609375	-0.2151154
3.27	6.5	5	0.3828125	-0.4170139
3.17	9.5	8	0.3046875	-0.5161454
3.06	13.5	12	0.21875	-0.6600519
3	17.5	16	0.171875	-0.7647873
2.93	21.5	20	0.1171875	-0.9311187
2.89	25.5	24	0.0859375	-1.0658173
				-0.4317983

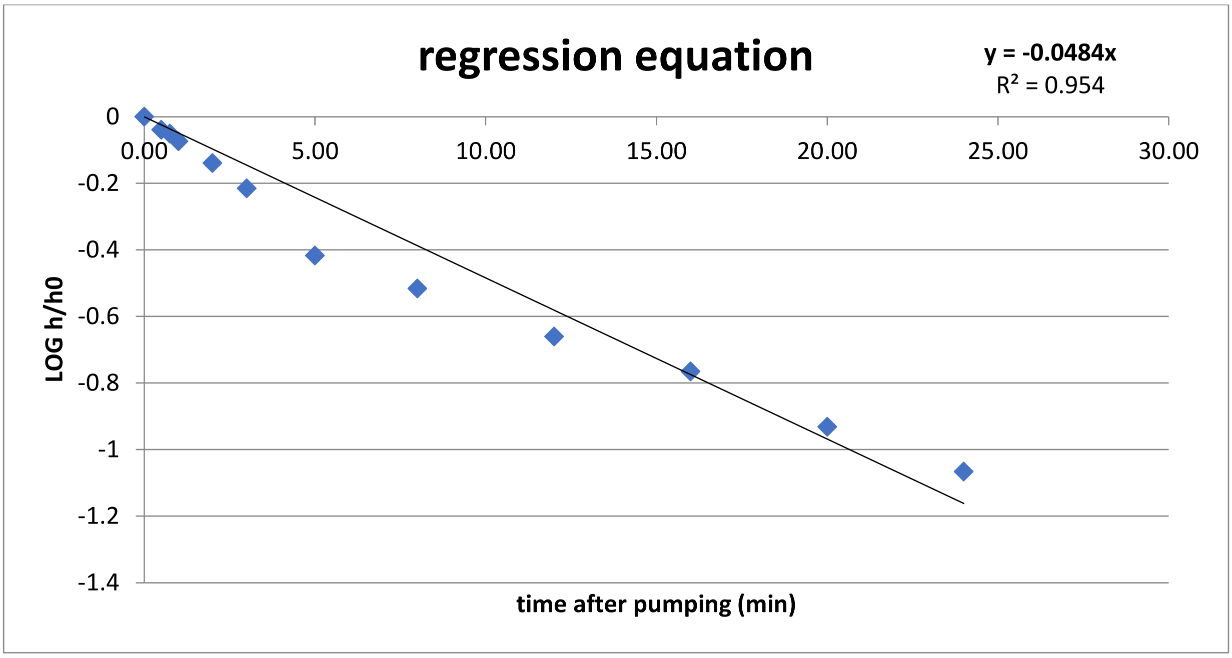

Fig 49: Regression equation for sludge test piezometer 5

Table 14: Sludge test piezometer 6

Time (minutes)	Groundwater level (m-GL)
0.5	4.05
0.75	4.04
1	4.03
2	4.02
3	4.0
5	3.99
8	3.96
12	3.94
16	3.94
20	3.93
24	3.91

Parameter	Value	Unit
piezometer	1	
pump duration	1.5	min
pumped volume (V)	3	l
pump flow (Q)	2.88	m³/d
level at rest (h0)	2.78	m
filter depth bottom	4.06	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.025	-
t37	17.27193104	min
K	5.42016E-05	m/min
K	**0.078050307**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.78	0	-	-	
4.06	1.5	0.00	1	0
4.05	2	0.5	0.9921875	-0.0034062
4.04	2.25	0.75	0.984375	-0.0068394
4.03	2.5	1	0.9765625	-0.0103
4.03	3.5	2	0.9765625	-0.0103
4.02	4.5	3	0.96875	-0.0137883
4	6.5	5	0.953125	-0.0208501
3.99	9.5	8	0.9453125	-0.0244246
3.96	13.5	12	0.921875	-0.035328
3.94	17.5	16	0.90625	-0.042752
3.93	21.5	20	0.8984375	-0.0465121
3.91	25.5	24	0.8828125	-0.0541315
				-0.4317983

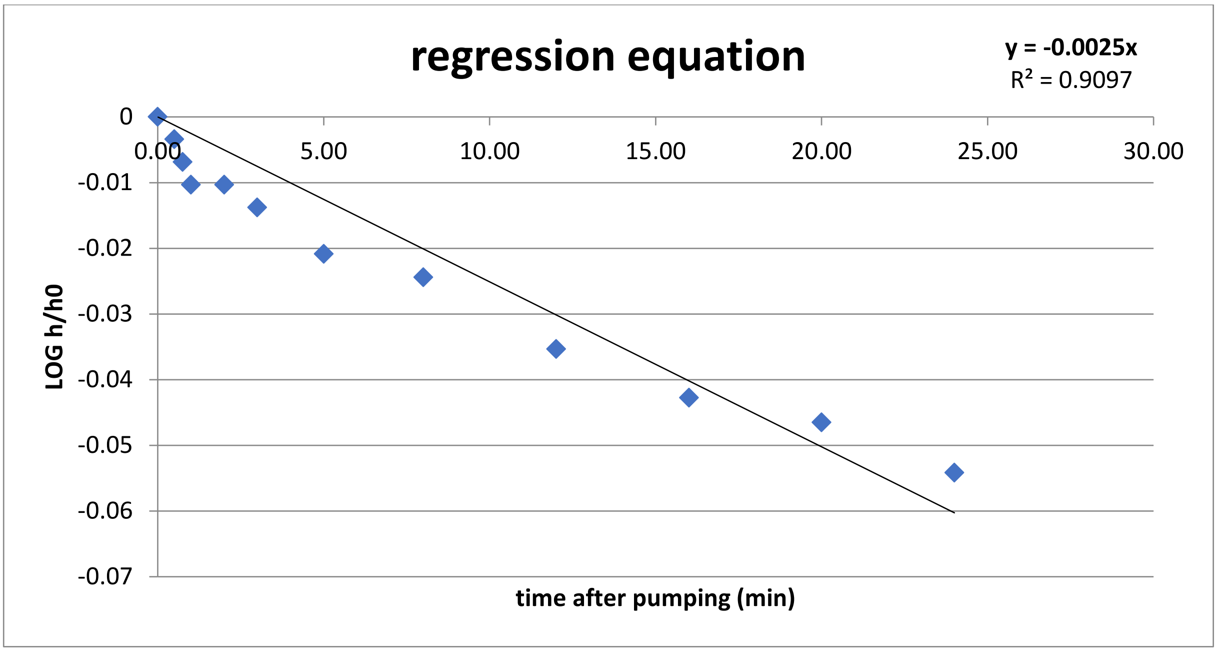

Fig. 50: Regression equation for sludge test piezometer 6

Table 15: Sludge test piezometer 7

Time (minutes)	**Groundwater level (m-GL)**
0.5	4.58
0.75	4.57
1	4.55
2	4.53
3	4.52
5	4.5
8	4..47
12	4.44
16	4.42
20	4.4
24	4.38

Parameter	Value	Unit
piezometer	1	
pump duration	1.616666667	min
pumped volume (V)	4	l
pump flow (Q)	3.56	m³/d
level at rest (h0)	2.83	m
filter depth bottom	4.6	m
fengt filter (fe)	1	m
r (m) (inner radius piezometer)	0.025	m
R (m) (radius borehole)	0.05	m
a (can be read from regeression equation)	-0.028	-
t37	15.421367	min
K	6.07058E-05	m/min
K	**0.087416344**	**m/d**

Groundwater level (h) (m)	time after pump start (t) (min)	time after the end of pumping (t') (min)	h/h0	log(h/h0)
2.83	0	-	-	
4.6	1.616666667	0.00	1	0
4.58	2.116666667	0.5	0.9887006	-0.0049352
4.57	2.366666667	0.75	0.9830508	-0.007424
4.55	2.616666667	1	0.9717514	-0.0124448
4.53	3.616666667	2	0.960452	-0.0175243
4.52	4.616666667	3	0.9548023	-0.0200866
4.5	6.616666667	5	0.9435028	-0.0252568
4.47	9.616666667	8	0.9265537	-0.0331294
4.44	13.61666667	12	0.9096045	-0.0411474
4.42	17.61666667	16	0.8983051	-0.0465761
4.4	21.61666667	20	0.8870056	-0.0520736
4.38	25.61666667	24	0.8757062	-0.0576416
				-0.4317983

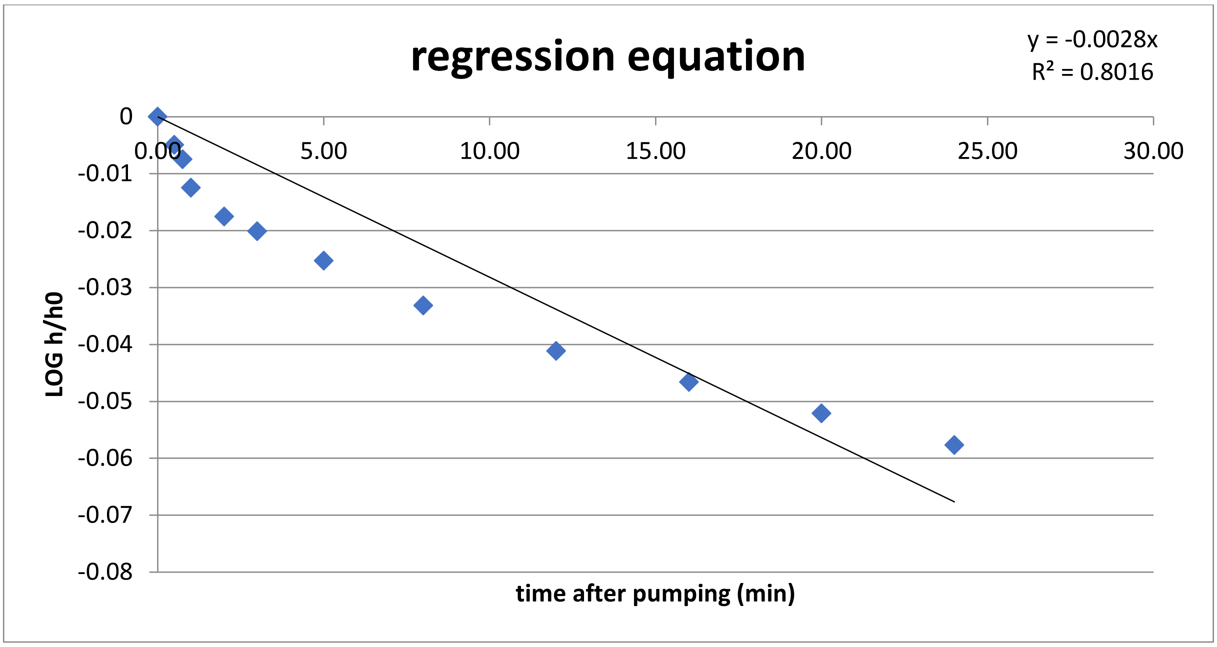

Fig. 51: Regression equation for sludge test piezometer 1

Granulometry

Piezometer 5

diameter < at X µm	accumulated fraction	piezometer number	5					
	% m/m ms	depth	200-300					
			Textural triangle				K m/s	K m/d
2000	99,91		sand	52,21	Hazen	$K = 0{,}0116\ d_{10}^2$	**2,18E-07**	**0,02**
1000	99,9				Seelheim	$K = 0{,}003557 d_{50}^2$	**1,65E-05**	**1,42**
500	99,7							
250	97,9							
125	76,6							
63	47,7		loam	38,5				
50	40,5							
45	37,9							
16	14							
2	9,2		clay	9,2				
d_{10}	4,333333333							
d_{50}	67,93425606							

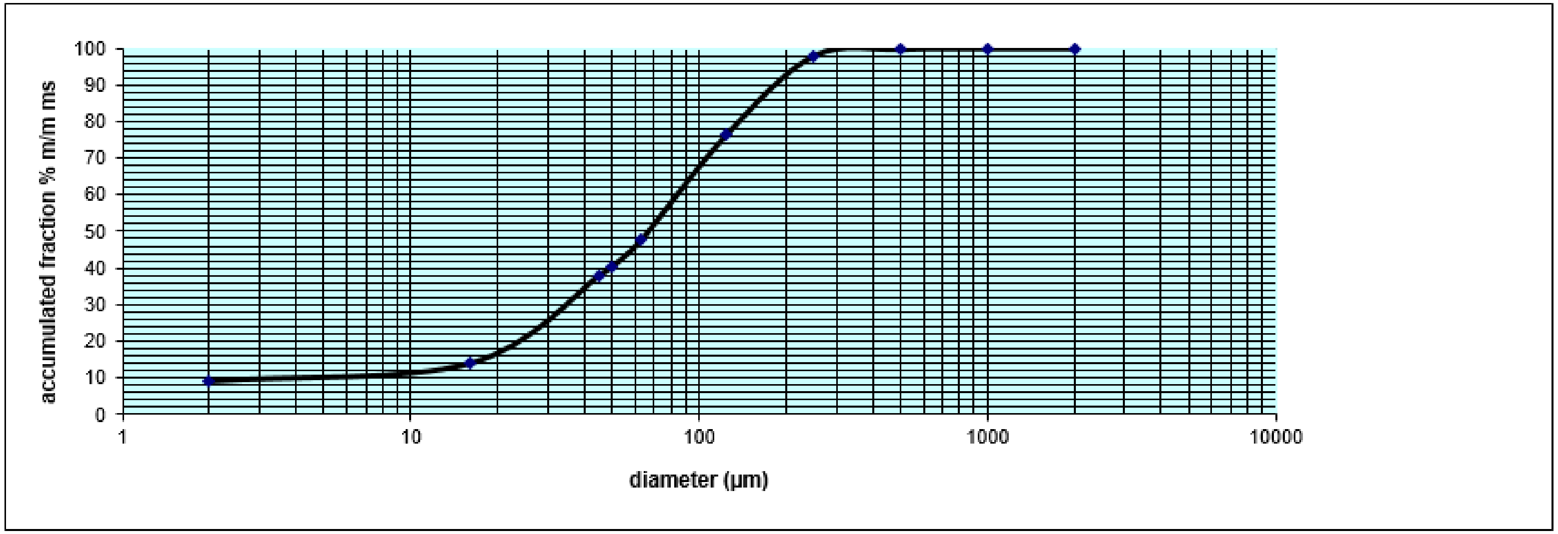

Fig. 52: Determining hydraulic conductivity (Hazen and Seelheim) according granulometry, piezometer 5

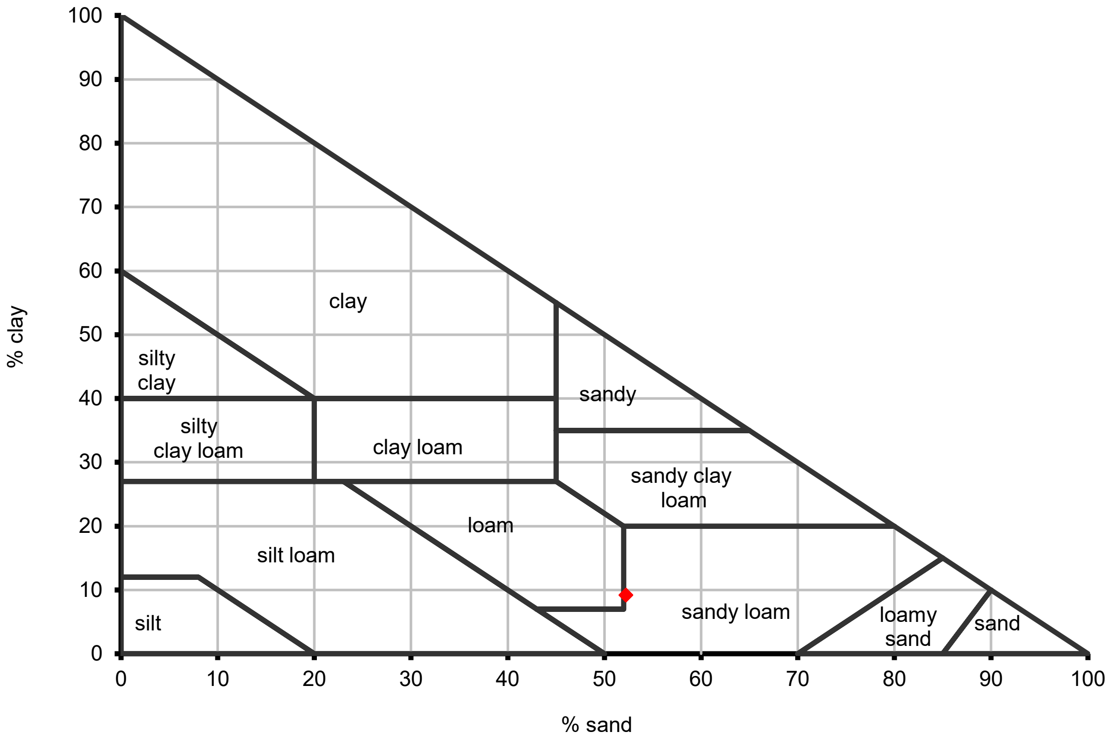

Fig. 53: Plots results of textural analysis piezometer 6 on textural triangle (Gerakis et al. 2000).

Piezometer 6

diameter < at X µm	accumulated fraction	piezometer number	6				
	% m/m ms	depth	200-300				
		textural triangle				K m/s	K m/d
2000	99,7	sand	69,8	Hazen	$K = 0{,}0116\ d_{10}^2$	**2,37E-06**	**0,21**
1000	99,5			Seelheim	$K = 0{,}003557 d_{50}^2$	**7,28E-05**	**6,29**
500	99						
250	90,9						
125	43,2						
63	29,9	loam	22,8				
50	27,6						
45	25,6						
16	10,4						
2	7,1	clay	7,1				
d_{10}	14,3030303						
d_{50}	142,8197065						

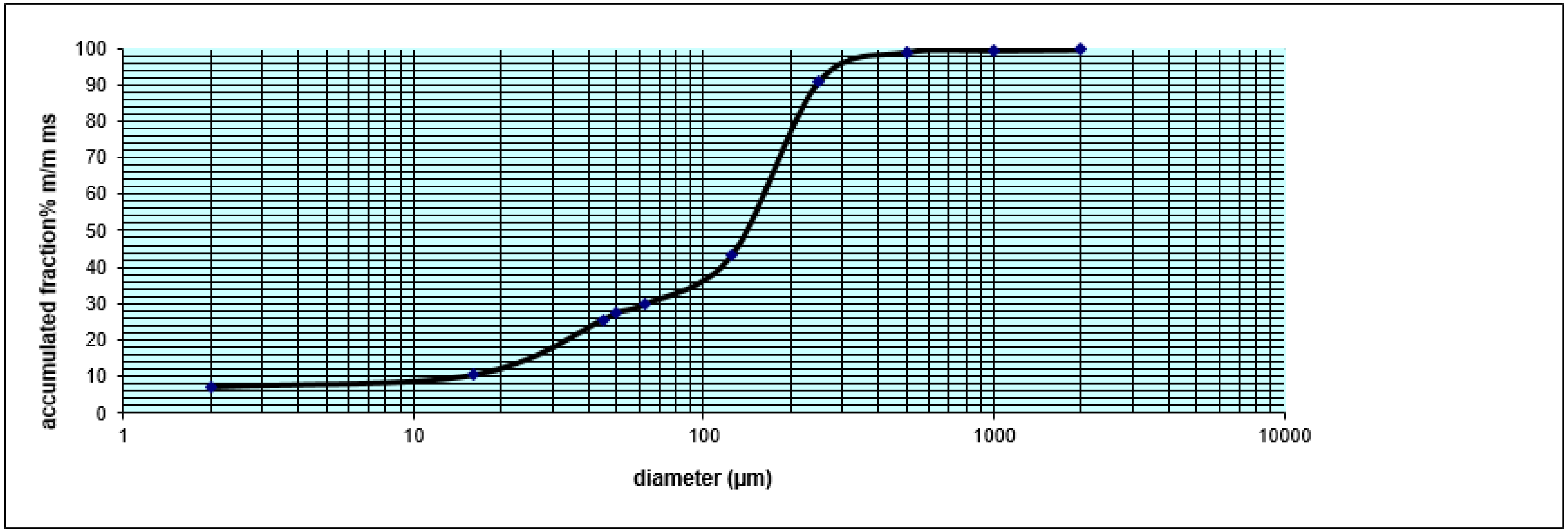

Fig. 54: Ddetermining hydraulic conductivity (Hazen and Seelheim) according granulometry, piezometer 6

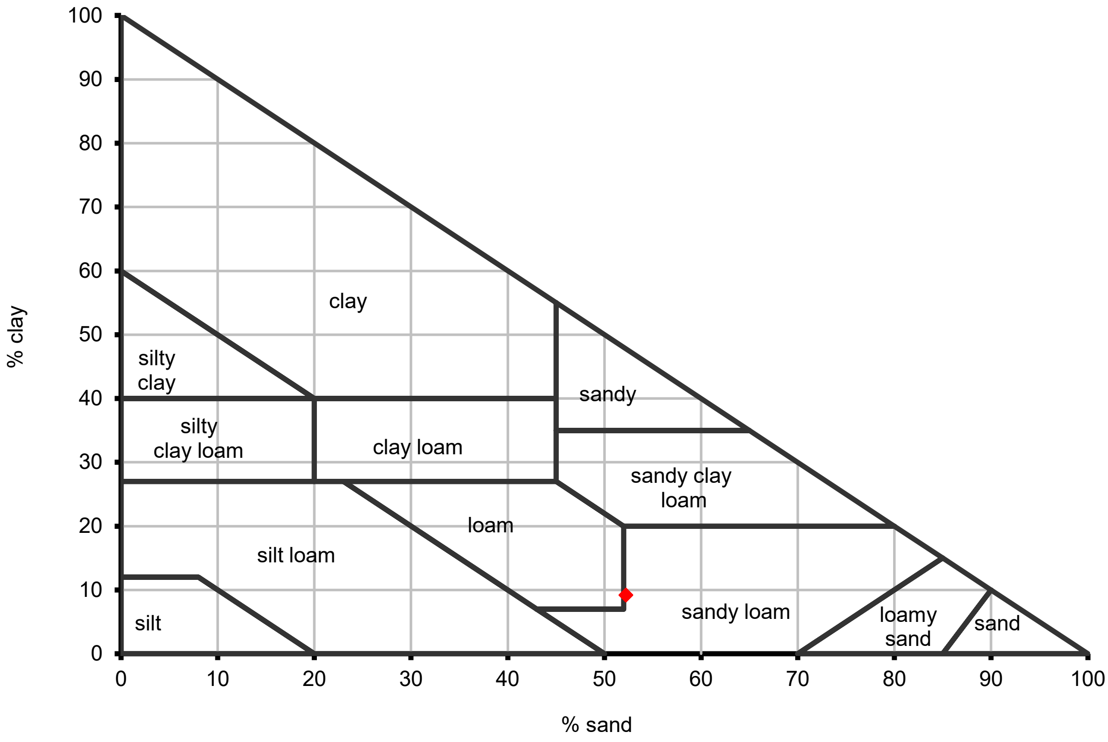

Fig. 55: Plots results of textural analysis piezometer 6 on textural triangle (Gerakis et al. 2000).

Attachement 4: Drill descriptions

Piezometer 1 Piezometer 2

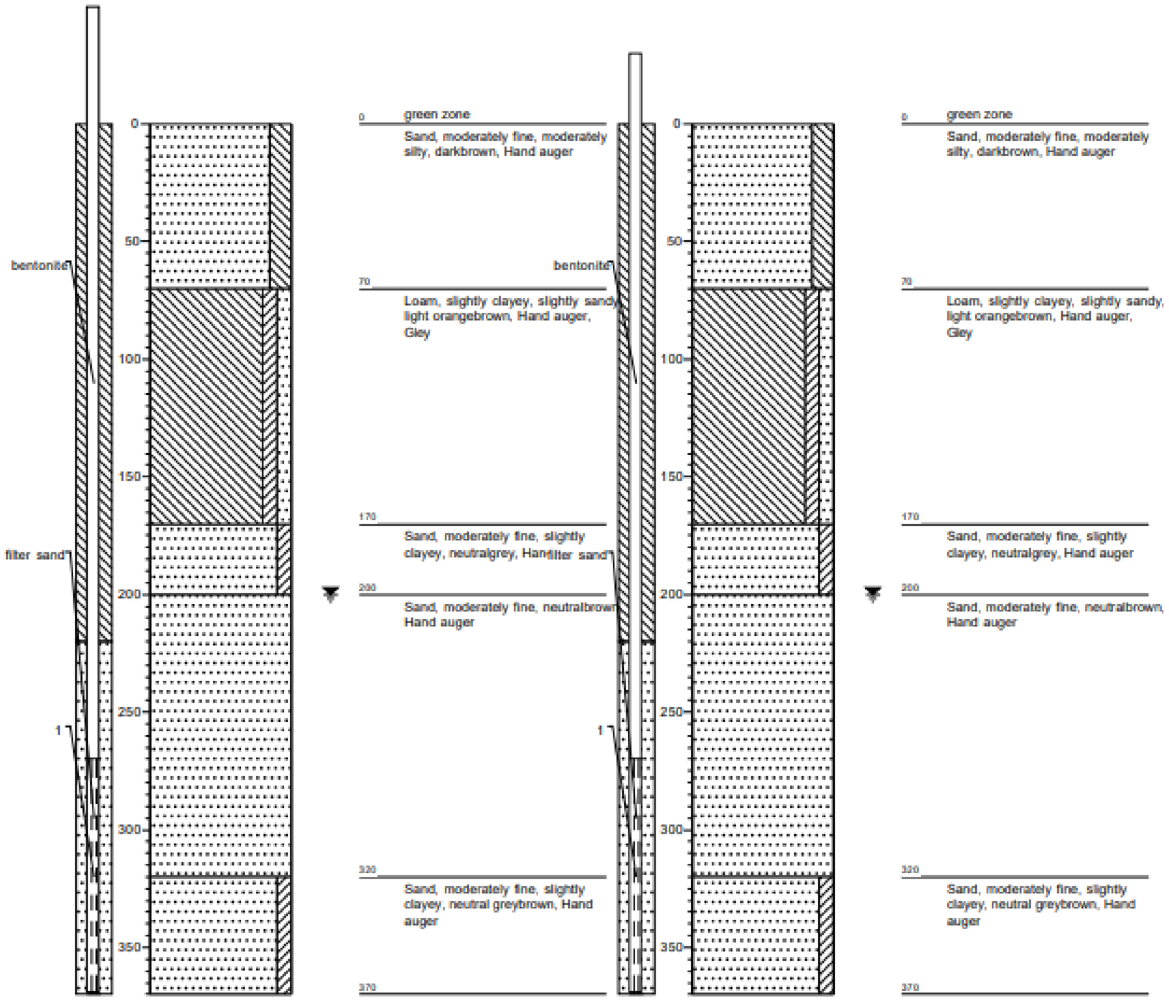

Fig. 56: Drill description piezometer 1 and 2

Piezometer 3 Piezometer 4

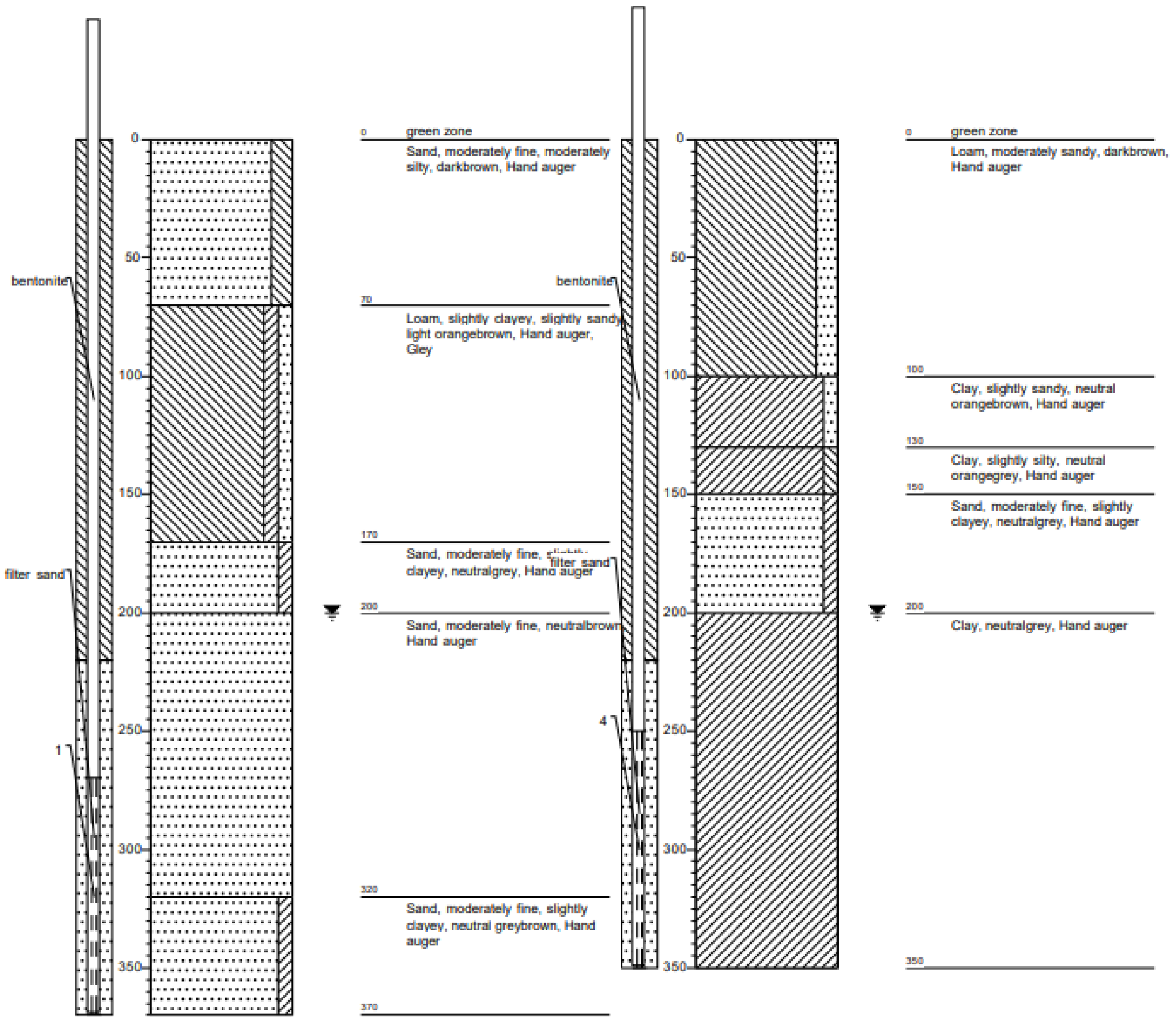

Fig. 57: Drill descriptions piezometers 3 and 4

Piezometer 5 Piezometer 6

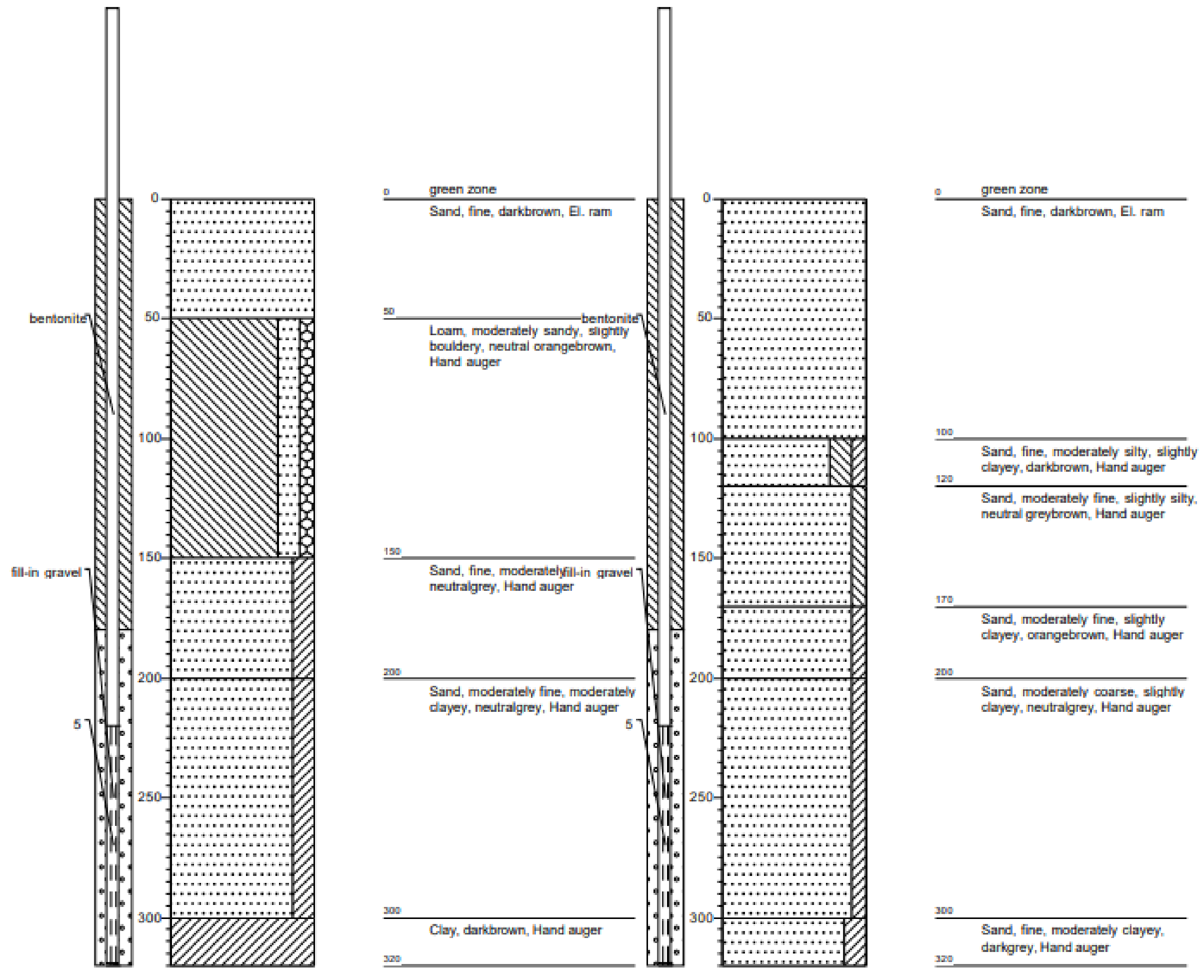

Fig. 58: Drill description piezometer 5 and 6

Piezometer 7

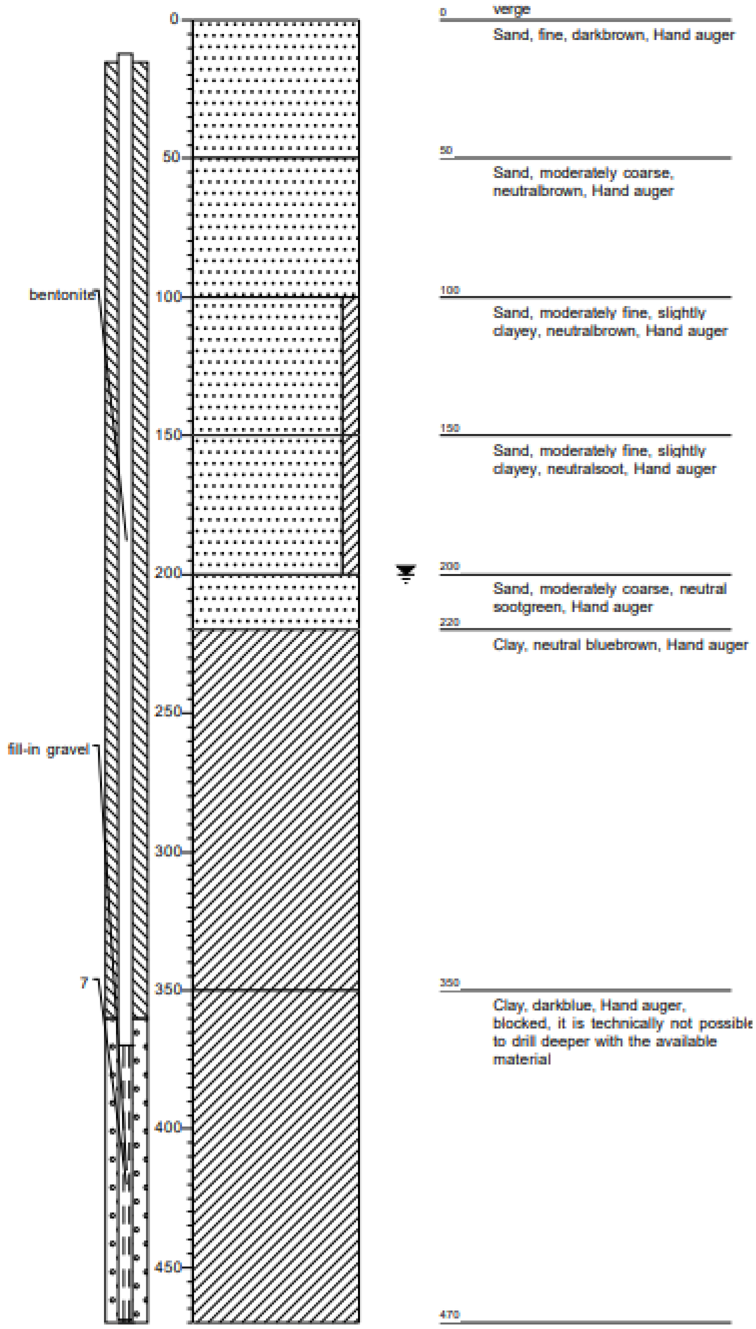

Fig. 59: Drill description piezometer 7

Attachment 5: Assessment tables

Table 16: Assessment table piezometer 1

Bore	**RV[7]**	**Unit**	**1**	**1**	**1**	**1**	**1**
Cadastral plot			820	820	820	820	820
Bore depth (m-GL)			3,70	3,70	3,70	3,70	3,70
Filter depth (m-GL)			2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7
Date sampling			15-06-2020	13-07-2020	24-08-2020	21-09-2020	12-10-2020
IN SITU MEASUREMENTS							
Depth groundwater (m-GL[8])	-		1,77	1,87	2,19	2,38	1,94
Temperature	-	°C	16,0	17,0	-	-	-
pH	-		5,48	5,4	-	-	-
Conductivity	1.250	µS/cm	525	517	-	-	-
O_2	-	mg/l	0,62	0,69	-	-	-
INORGANIC COMPOUNDS							
Ammonium	1	mg/l	0,14	< 0,13	<0,13	<0,13	<0,013
Nitrite (as NO_2^-)	0,1	mg/l	**0,13**	**0,14**	**0,15**	**0,12**	0,092
Nitrate (as NO_3^-)	50	mg/l	**58,0**	**87,4**	**59,4**	**56**	**79,1**

Table 17: Assessment table piezometer 2

Bore	**RV[7]**	**Unit**	**2**	**2**	**2**	**2**	**2**
Cadastral plot			820	820	820	820	820
Bore depth (m-GL)			3,50	3,50	3,50	3,50	3,50
Filter depth (m-GL)			2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7
Date sampling			15-06-2020	13-07-2020	24-08-2020	21-09-2020	12-10-2020
IN SITU MEASUREMENTS							
Depth groundwater (m-GL)	-		1,90	2,02	2,3	2,48	2,02
Temperature	-	°C	13,3	16,40	-	-	-
pH	-		5,44	5,35	-	-	5,41
Conductivity	1.250	µS/cm	519	537	-	-	575
O_2	-	mg/l	-	2,01	-	-	-
INORGANIC COMPOUNDS							
Ammonium	1	mg/l	< 0,13	< 0,13	<0,13	0,13	<0,013
Nitrite (as NO_2^-)	0,1	mg/l	0,066	0,049	0,043	<0,035	0,036
Nitrate (as NO_3^-)	50	mg/l	**101**	**96**	**99,5**	**97,8**	**88,7**

[7] AV: reference value
[8] m-GL = meter - groundlevel

Table 18: Assessment table piezometer 3

Bore	**RV**[7]	**Unit**	**3**	**3**	**3**	**3**	**3**
Cadastral plot			820	820	820	820	820
Bore depth (m-GL)			3,70	3,70	3,70	3,70	3,70
Filter depth (m-GL)			2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7	2,7-3,7
Date sampling			15-06-2020	13-07-2020	24-08-2020	21-09-2020	12-10-2020
IN SITU MEASUREMENTS							
Depth groundwater (m-GL)	-		1,83	1,88	2,11	2,31	1,78
Temperature	-	°C	13,0	-	-	-	-
pH	-		5,7	-	-	-	-
Conductivity	1.250	µS/cm	-	-	-	-	-
O_2	-	mg/l	-	-	-	-	-
INORGANIC COMPOUNDS							
Ammonium	1	mg/l	<0,13	< 0,13	< 0,13	< 0,13	< 0,13
Nitrite (as NO_2^-)	0,1	mg N/l	**0,85**	< 0,11	< 0,035	< 0,035	< 0,035
Nitrate (as NO_3^-)	50	mg/l	**54,5**	**54,9**	**59,2**	**60,4**	**60,5**

Table 19: Assessment table piezometer 4

Bore	**RV**[7]	**Unit**	**4**	**4**	**4**	**4**	**4**
Cadastral plot			820	820	820	820	820
Bore depth (m-GL)			3,50	3,50	3,50	3,50	3,50
Filter depth (m-GL)			2,5-3,5	2,5-3,5	2,5-3,5	2,5-3,5	2,5-3,5
Date sampling			15-06-2020	13-07-2020	24-08-2020	21-09-2020	12-10-2020
IN SITU MEASUREMENTS							
Depth groundwater (m-GL)	-		1,39	1,28	1,56	1,77	0,98
Temperature	-	°C	16	17,5	-	-	-
pH	-		6,1	5,96	-	-	-
Conductivity	1.250	µS/cm	649	611	-	-	-
O_2	-	mg/l	-	1,58	-	-	-
INORGANIC COMPOUNDS							
Ammonium	1	mg/l	< 0,13	<0,13	< 0,13	< 0,13	< 0,13
Nitrite (as NO_2^-)	0,1	mg N/l	<0,040	< 0,035	<0,035	<0,035	<0,035
Nitrate (as NO_3^-)	50	mg/l	1,77	1,96	1,71	0,62	0,12

Table 20: Assessment table piezometer 5

Bore	**RV**[7]	**Unit**	**5**	**5**
Cadastral plot			820	820
Bore depth (m-GL)			3,20	3,20
Filter depth (m-GL)			2,2-3,2	2,2-3,2
Date sampling			21-09-2020	12-10-2020
IN SITU MEASUREMENTS				
Depth groundwater (m-GL)	-		1,44	1,02
Temperature	-	°C	-	-
pH	-		-	-
Conductivity	1.250	µS/cm	-	-
O_2	-	mg/l	-	-
INORGANIC COMPOUNDS				
Ammonium	1	mg/l	<0,013	< 0,13
Nitrite (as NO_2^-)	0,1	mg N/l	**0,21**	0,039
Nitrate (as NO_3^-)	50	mg/l	**116**	122

Table 21: Assessment table piezometer 6

Bore	**RV**[7]	**Unit**	**6**	**6**
Cadastral plot			820	820
Bore depth (m-GL)			3,20	3,20
Filter depth (m-GL)			2,2-3,2	2,2-3,2
Date sampling			21-09-2020	12-10-2020
IN SITU MEASUREMENTS				
Depth groundwater (m-GL)	-		1,89	1,23
Temperature	-	°C	-	-
pH	-		-	-
Conductivity	1.250	µS/cm	-	-
O_2	-	mg/l	-	-
INORGANIC COMPOUNDS				
Ammonium	1	mg/l	<0,013	< 0,13
Nitrite (as NO_2^-)	0,1	mg N/l	<0,035	<0,035
Nitrate (as NO_3^-)	50	mg/l	1,89	0,28

Table 22: Assessment table piezometer 7

Bore	**RV**[7]	**Unit**	**7**	**7**
Cadastral plot			820	820
Bore depth (m-GL)			4,70	4,70
Filter depth (m-GL)			3,7-4,7	3,7-4,7
Date sampling			21-09-2020	12-10-2020
IN SITU MEASUREMENTS				
Depth groundwater (m-GL)	-		2,97	2,9
Temperature	-	°C	-	-
pH	-		-	-
Conductivity	1.250	µS/cm	-	-
O_2	-	mg/l	-	-
INORGANIC COMPOUNDS				
Ammonium	1	mg/l	0,45	0,50
Nitrite (as NO_2^-)	0,1	mg N/l	<0,035	<0,035
Nitrate (as NO_3^-)	50	mg/l	<0,045	<0,045

Attachment 6: Precipitation near research location

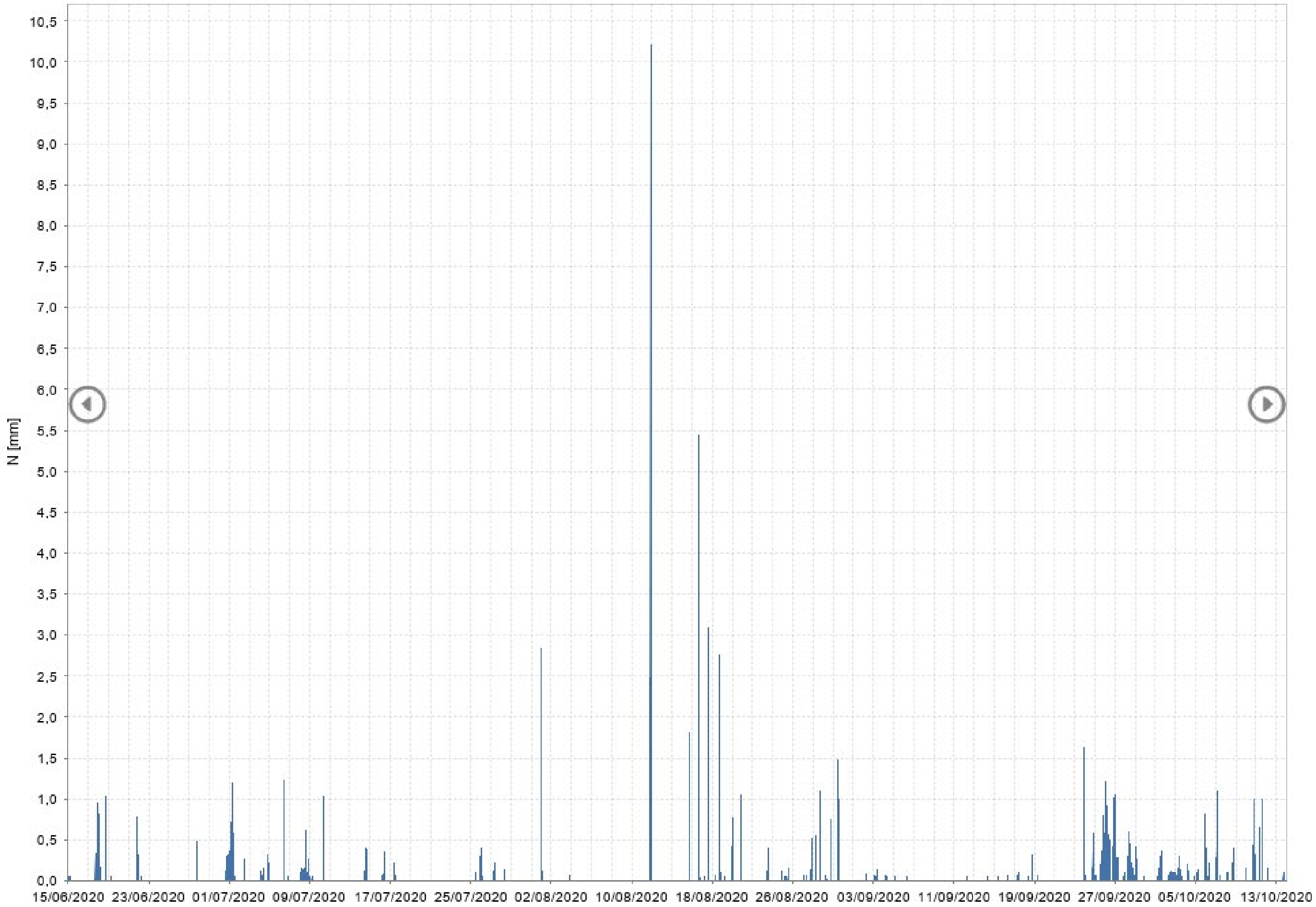

Fig. 60: Precipitation 15/06/2020 to 12/10/2020 pluvial measuring point plu02a-1066, Bornem[9] (source: https://www.waterinfo.be/default.aspx?path=NL/Rapporten/Downloaden&KL=en)

[9] Measuring point plu02a-1066, Bornem is the closest nearby the research location

Attachment 7: Graphs nitrate concentration per piezometer

Red line in following graphs is indicating the reference value for nitrate (50 mg/L)in groundwater.

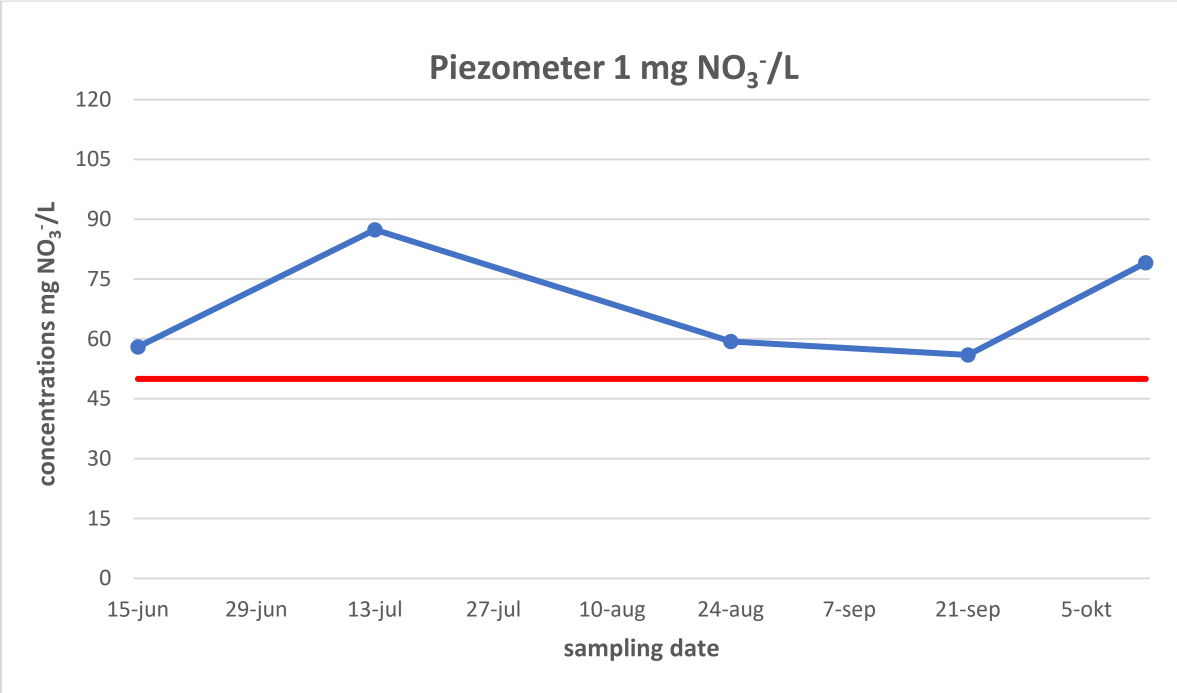

Fig 61. : Concentration (mg/L) nitrate in piezometer 1, sampling period: 15/06/2020 → 12/10/2020

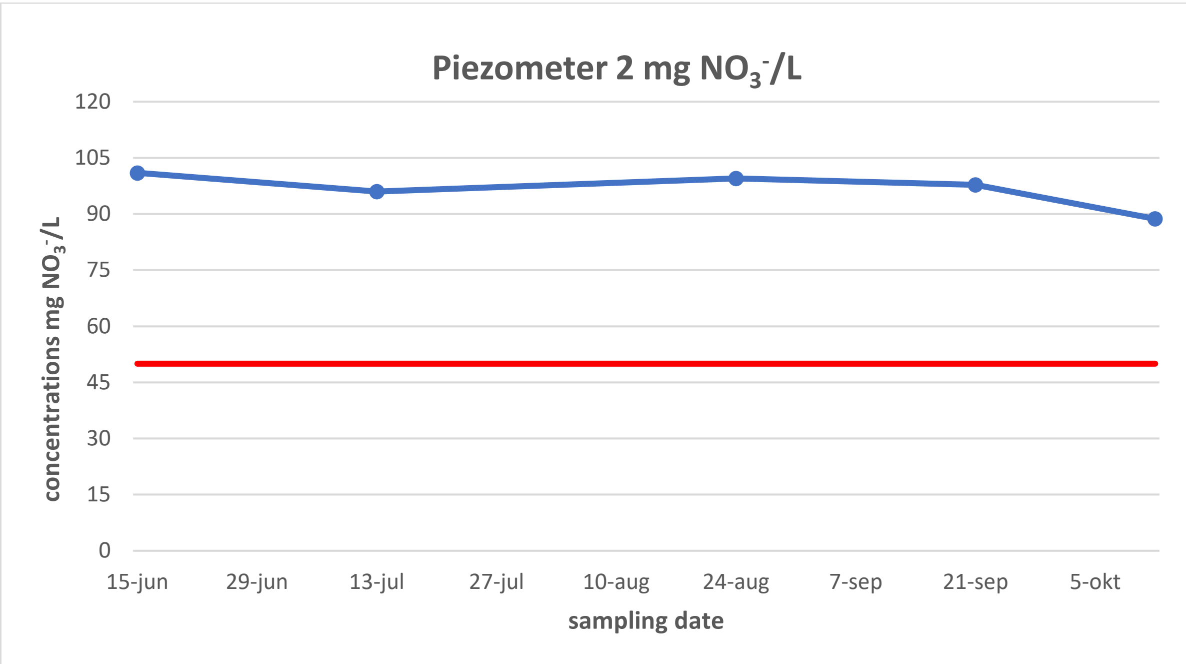

Fig. 62: Concentration (mg/L) nitrate in piezometer 2, sampling period: 15/06/2020 → 12/10/2020

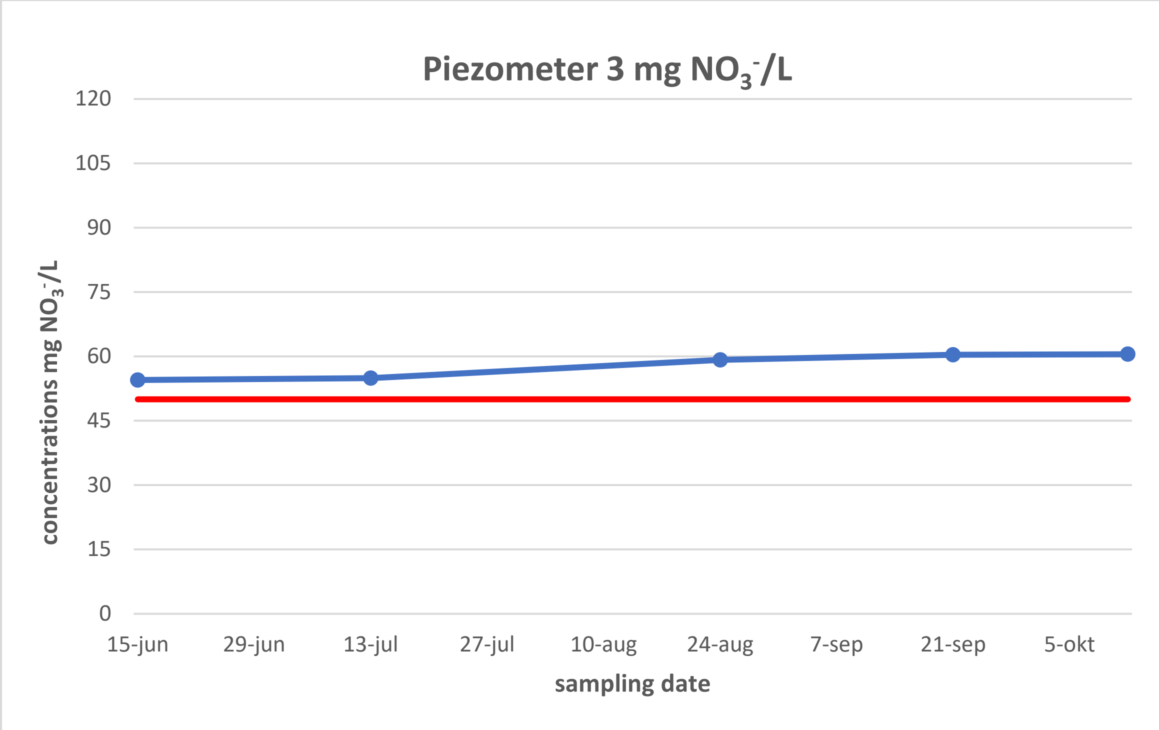

Fig. 63: Concentration (mg/L) nitrate in piezometer 3, sampling period: 15/06/2020 → 12/10/2020

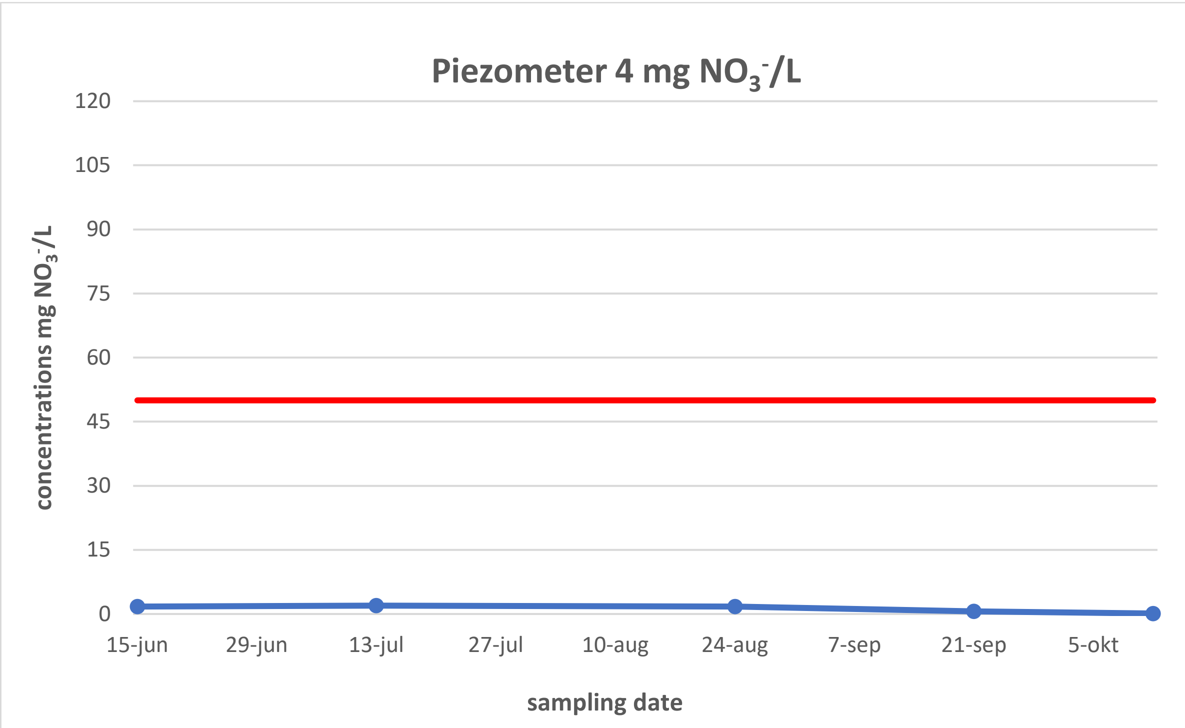

Fig. 64: Concentration (mg/L) nitrate in piezometer 4, sampling period: 15/06/2020 → 12/10/2020

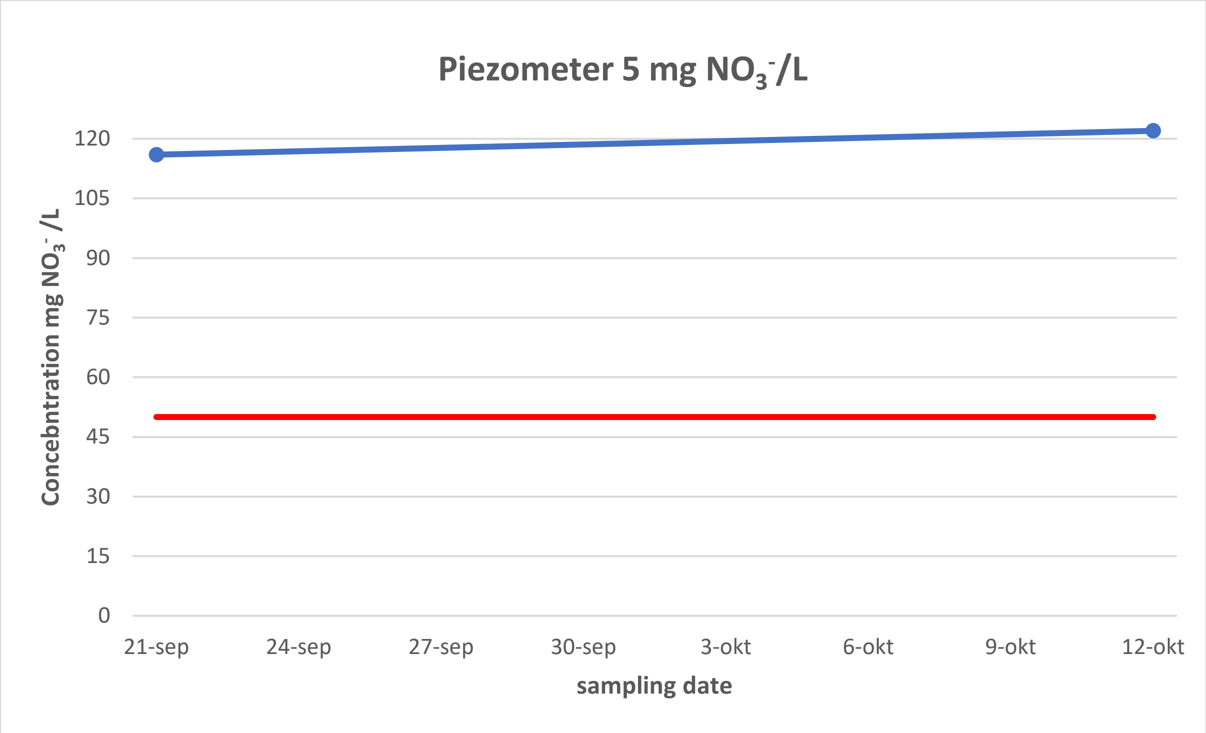

Fig. 65: Concentration (mg/L) nitrate in piezometer 5, sampling period: 21/09/2020 → 12/10/2020

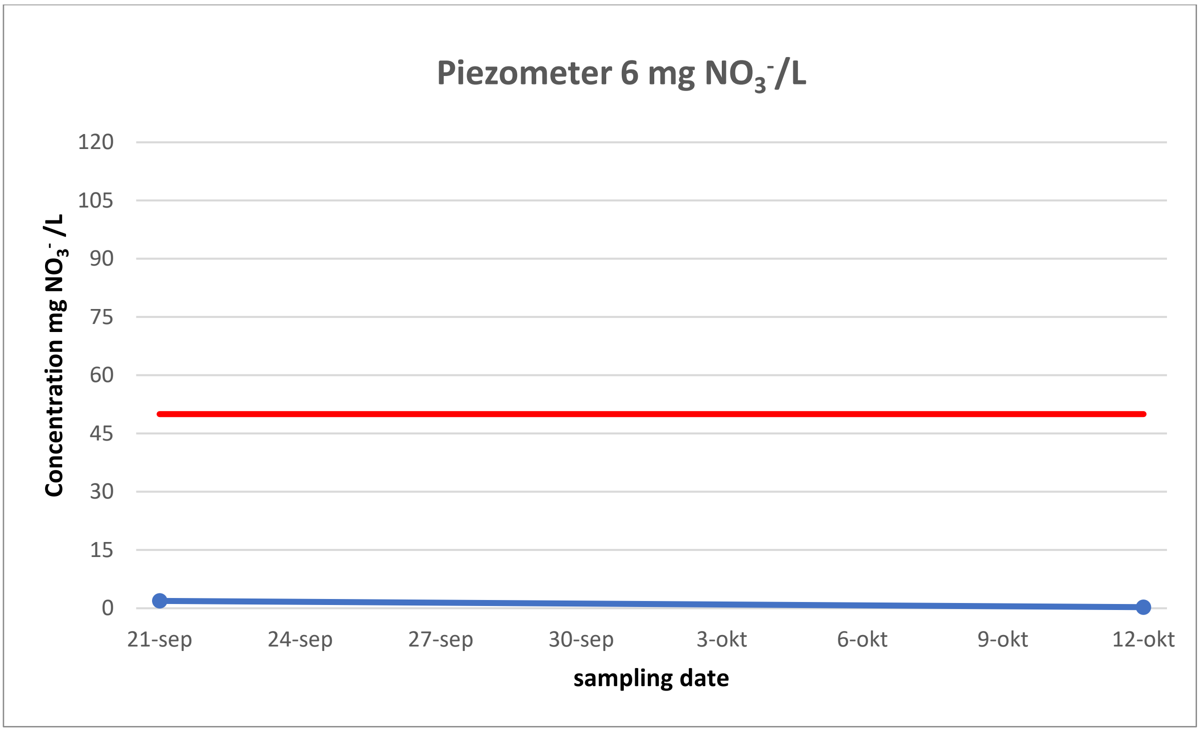

Fig. 66: Concentration (mg/L) nitrate in piezometer 6, sampling period: 21/09/2020 → 12/10/2020

Attachment 8: Graphs, nitrate concentrations per sampling day

Red line in following graphs is indicating the reference value for nitrate (50 mg/L) in groundwater.

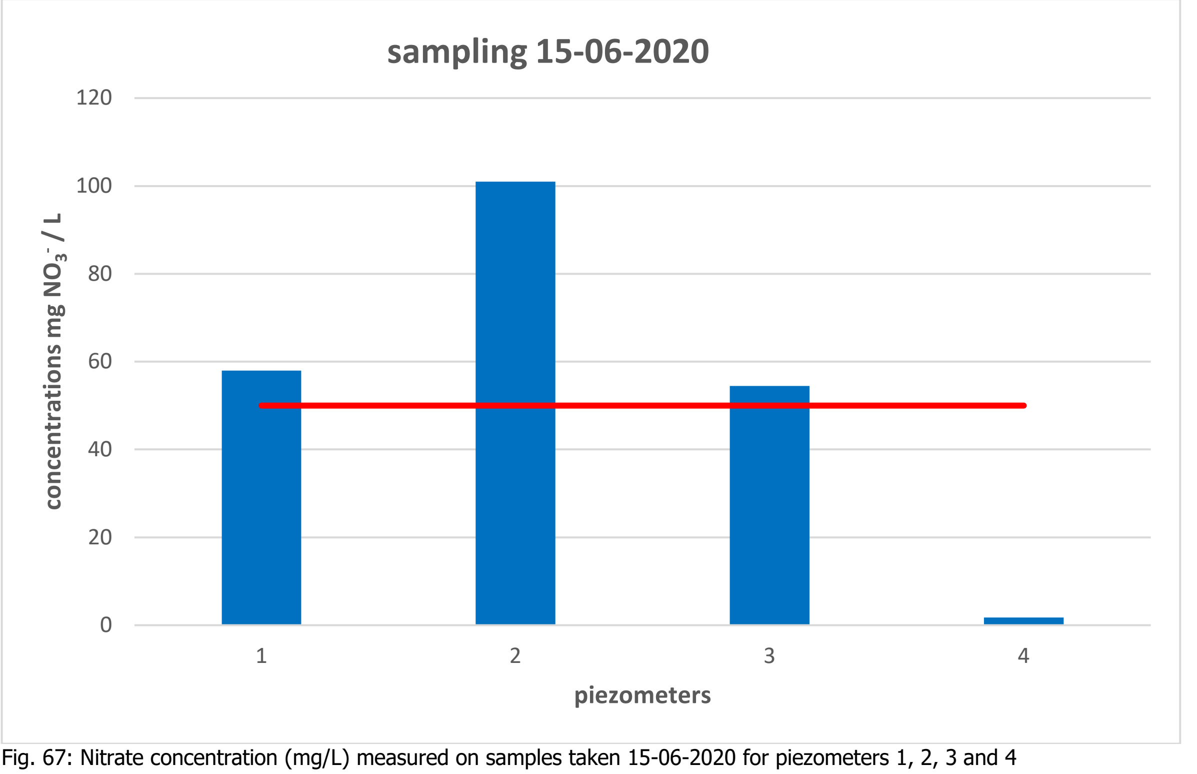

Fig. 67: Nitrate concentration (mg/L) measured on samples taken 15-06-2020 for piezometers 1, 2, 3 and 4

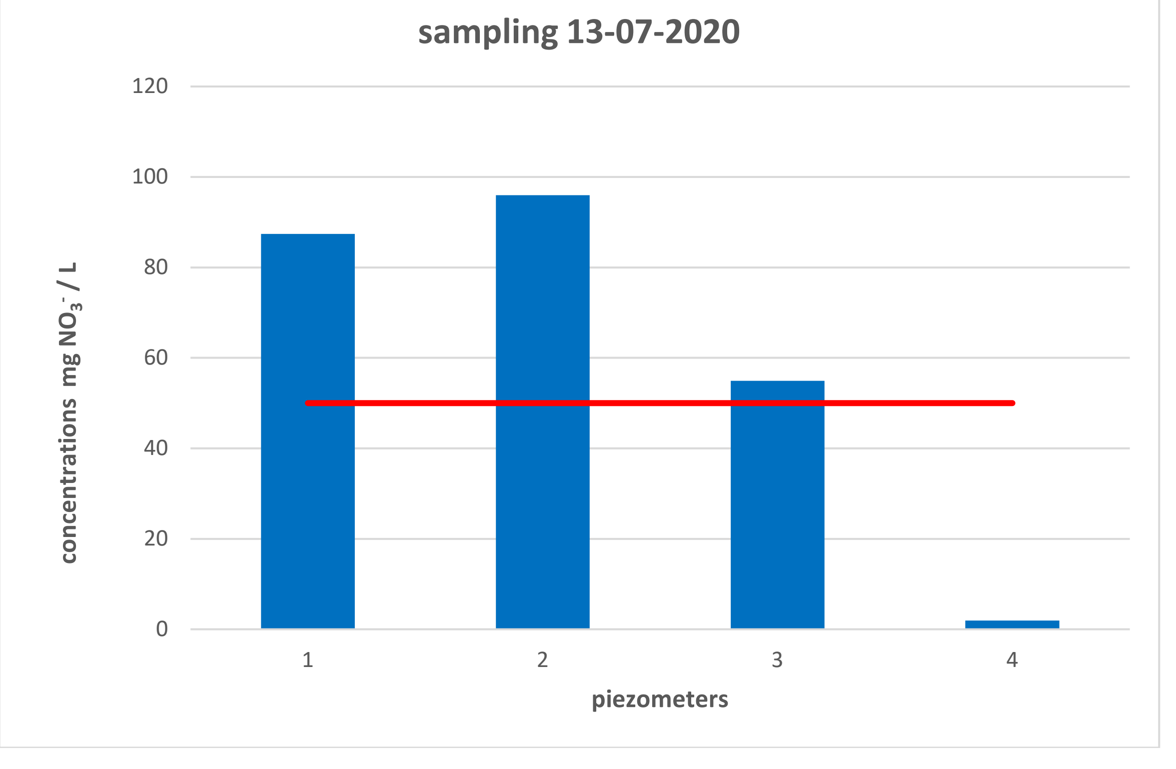

Fig. 68: Nitrate concentration (mg/L) measured on samples taken 13-07-2020 for piezometers 1, 2, 3 and 4

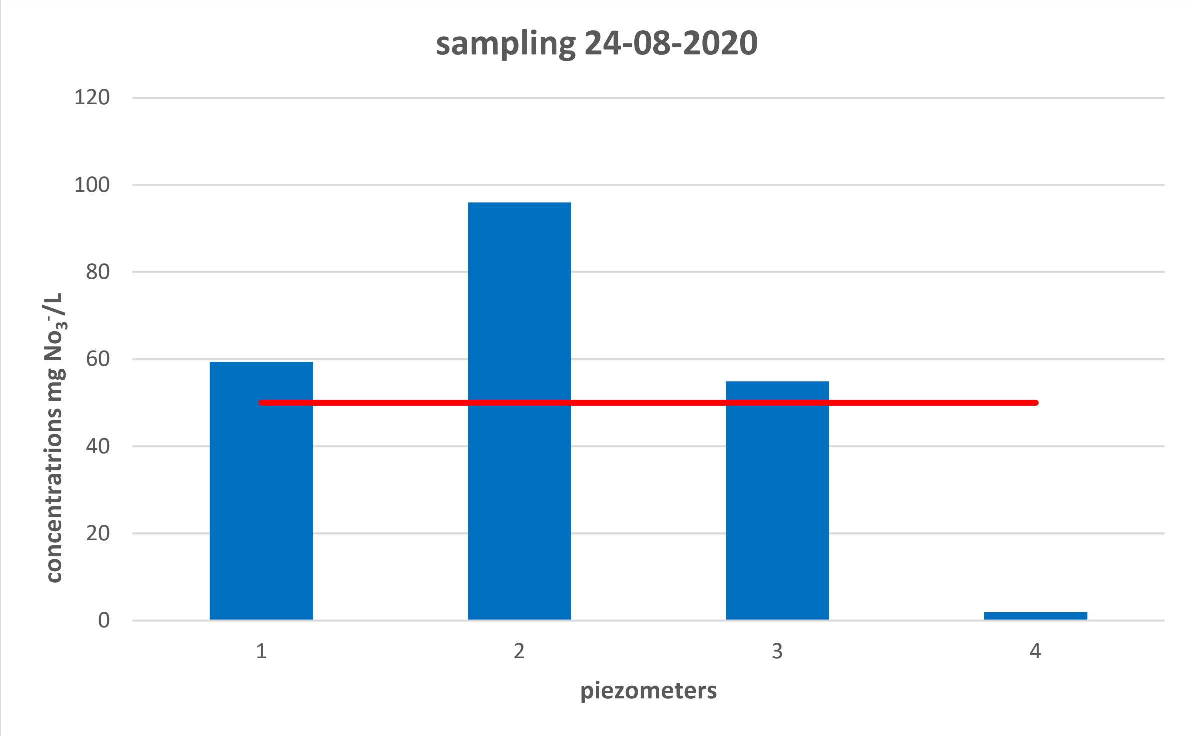

Fig. 69: Nitrate concentration (mg/L) measured on samples taken 24-08-2020 for piezometers 1, 2,3 and 4

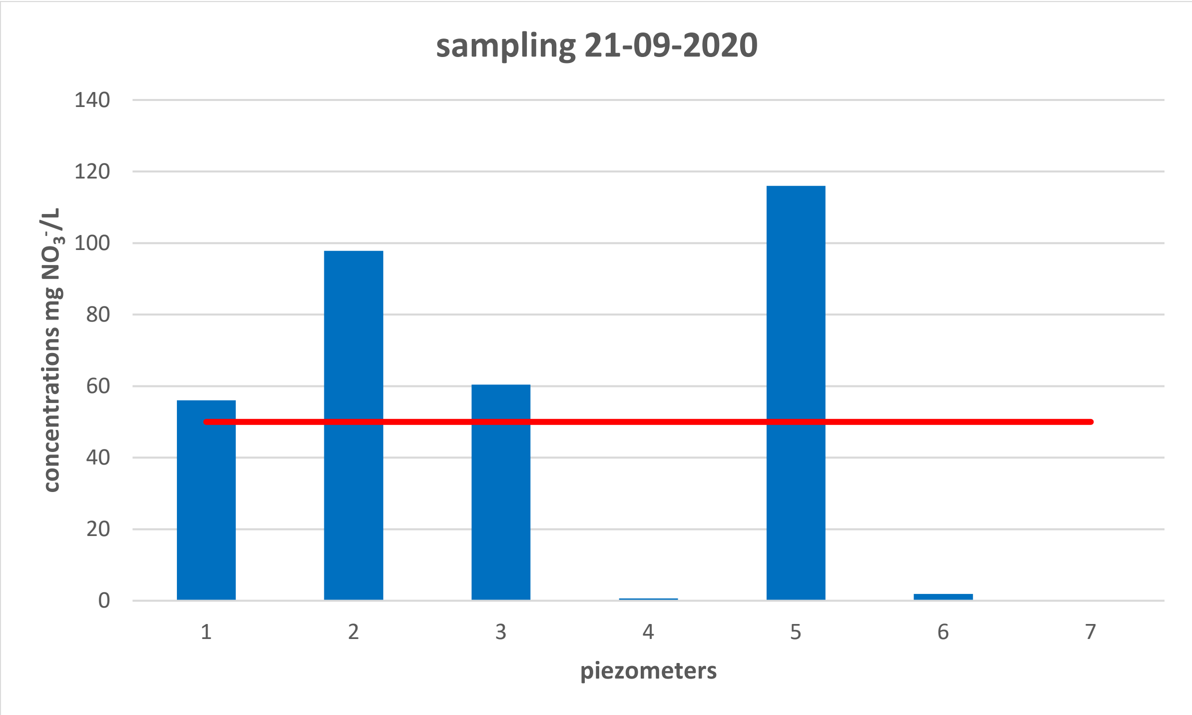

Fig. 70: Nitrate concentration (mg/L) measured on samples taken 21-09-2020 for piezometers 1, 2,3, 4, 5, 6 and 7

Fig. 71: Nitrate concentration (mg/L) measured on samples taken 12-10-2020 for piezometers 1, 2,3, 4, 5, 6 and 7

Attachment 9: Run-off

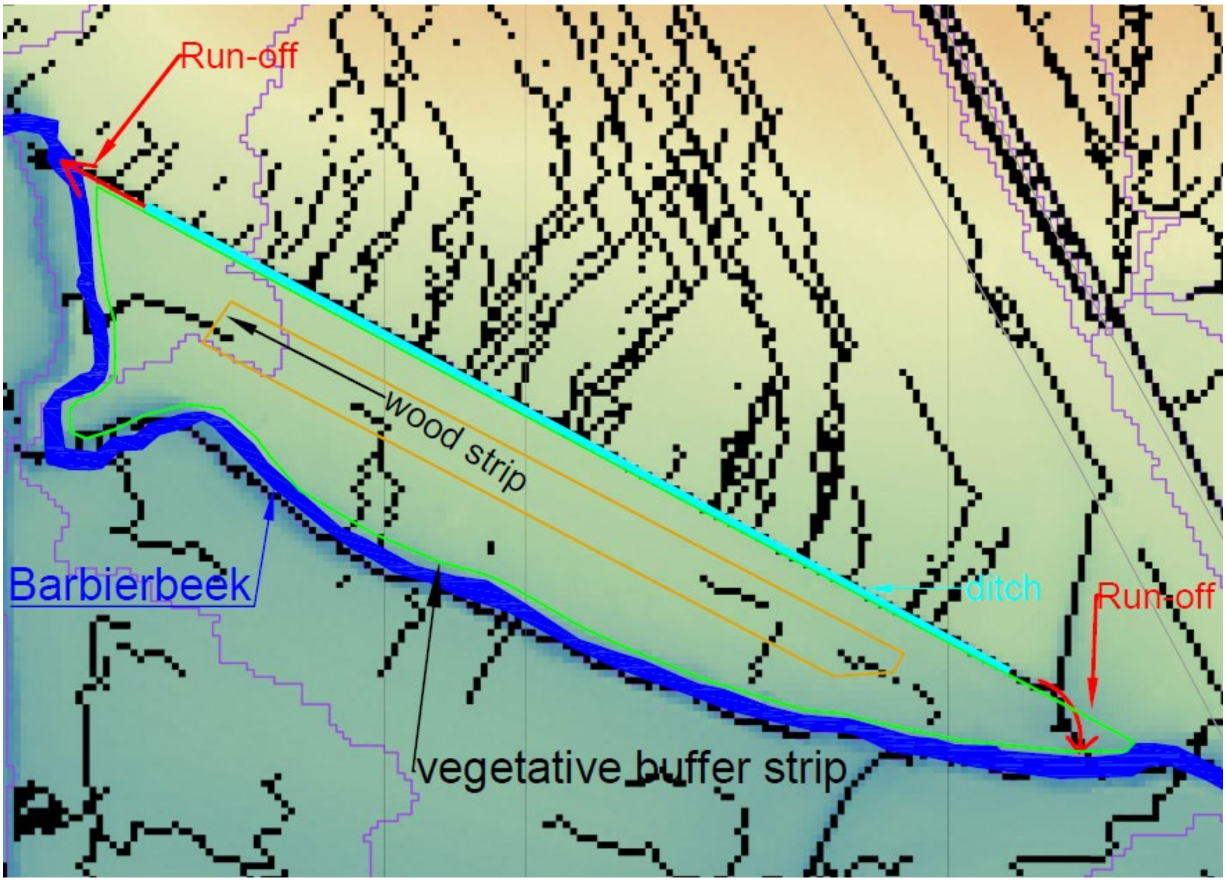

Fig. 72: Representation of run-off within the watersheds near the vegetative buffer strip and the Barbierbeek, the black lines are indicating the run-off pathways.

Fig. 73 Ditch with run-off towards Barbierbeek dd. 07/02/2020

Attachment 10: Localisation pictures

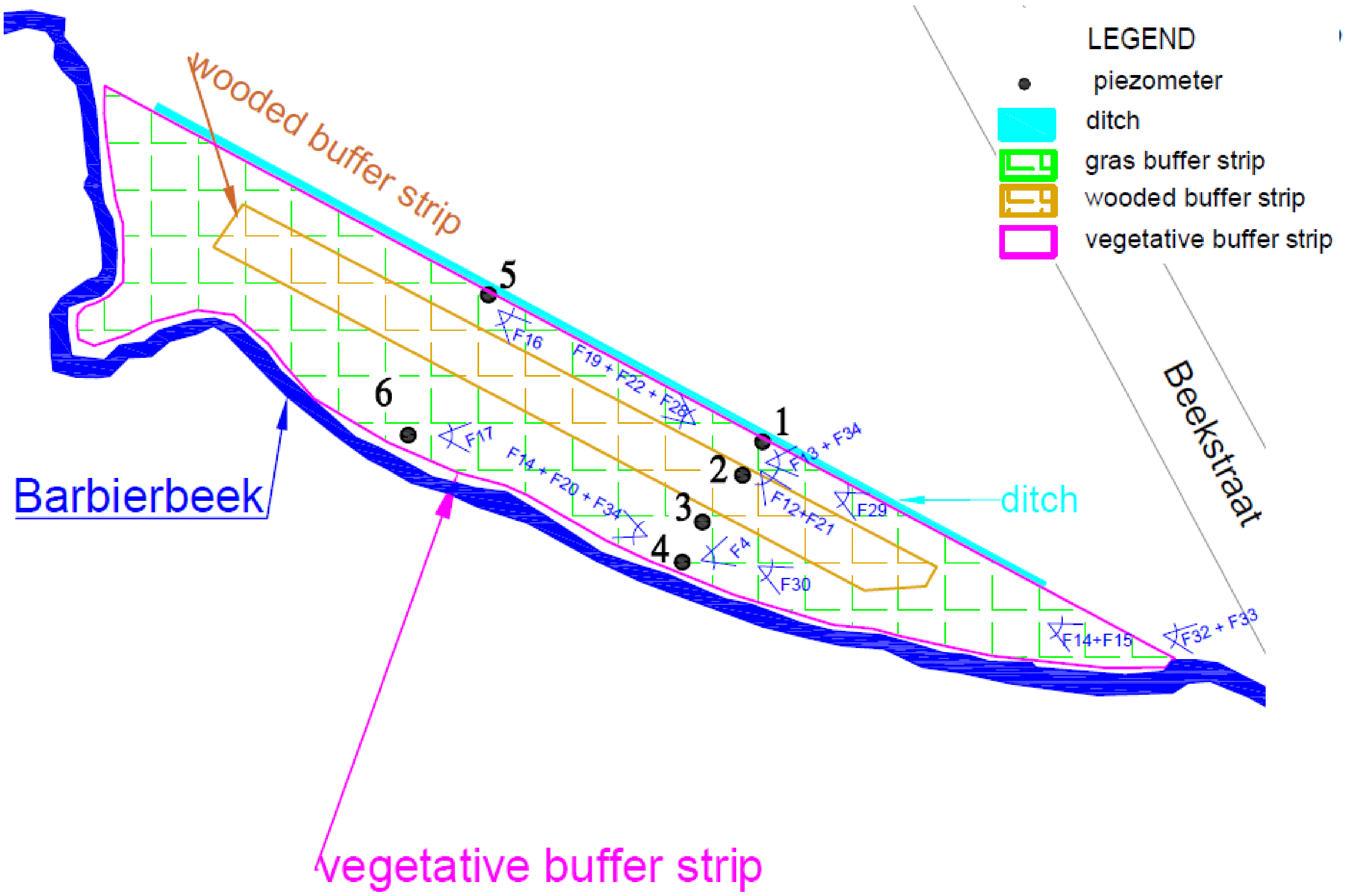

Fig. 74: Localisation of taken photos

Attachment 11: Press release VLM dd; 4/12/2020

Nog te veel stikstof in het water in landbouwgebied door verkeerde bemestingspraktijken

Vrijdag 4 december 2020 — **Uit het recente Mestrapport van de Vlaamse Landmaatschappij blijkt dat de waterkwaliteit in landbouwgebied achteruit gaat. Halverwege het 6de mestactieprogramma (MAP 6) zijn we verder verwijderd van de waterkwaliteitsdoelstellingen dan bij de start. Aan de basis van die ongunstige evolutie liggen de bemestingspraktijken. Om de Europese waterkwaliteitsdoelstellingen op termijn te realiseren, moeten de bemestingspraktijken dringend duurzamer worden. Daarbij moeten landbouwers meer rekening houden met de veranderende weersomstandigheden.**

Waterkwaliteit in landbouwgebied gaat achteruit

Uit de meest recente cijfers van de Vlaamse Milieumaatschappij (VMM) in het Mestrapport 2020 blijkt dat de kwaliteit van het oppervlaktewater in landbouwgebied achteruit gaat. Al drie winterjaren op rij ligt het percentage meetpunten met een overschrijding van de drempelwaarde van 50 mg nitraat per liter ruim boven de 20%. Waar MAP 6 een verbetering van minstens 4 mg nitraat per liter voorop stelt tegen 2022 in gebieden met een ongunstige waterkwaliteit, stellen we in 2020 een verslechtering van 4 mg nitraat per liter vast in die gebieden. Ook blijkt dat voor 23% van het landbouwgebied de nitraatgehalten in het grondwater onvoldoende dalen. Halverwege MAP 6 liggen de waterkwaliteitsdoelstellingen verder af dan bij de start.

Slimmer bemesten en vanggewassen inzaaien

Het Mestrapport maakt duidelijk dat de bemestingspraktijken aan de basis liggen van hoge nitraatresidu's in de bodem in het najaar. Het gemiddelde nitraatresidu is de laatste drie jaren gestegen tot 85 kg nitraatstikstof per hectare in 2019. Het verbeteren van de bemestingspraktijken volgens het principe van de 4J's staat nochtans centraal: bemesten met de juiste dosis, de juiste mestsoort, op het juiste tijdstip en met de juiste bemestingstechniek. Daarnaast is het inzaaien van een vanggewas na de oogst van de hoofdteelt een goede praktijk om het resterende nitraat in de bodem op te nemen. Het is de verantwoordelijkheid van elke landbouwer om de bemesting slim en juist uit te voeren en maximaal vanggewassen te zaaien om het nitraatresidu zo laag mogelijk te krijgen. Landbouwers die deze praktijken hanteren, zijn ook beter gewapend tegen onvoorziene weersomstandigheden.

Beter inspelen op het veranderend klimaat

De droge weersomstandigheden van de voorbije jaren hebben ongetwijfeld een invloed op de recente evolutie van de waterkwaliteit. Lange droogteperiodes in het groeiseizoen leiden immers tot minder opname van stikstof door de gewassen en bijgevolg tot een hoger nitraatresidu en een hoger risico op uitspoeling van nitraten naar het water. Het weer is evenwel een factor waar landbouwers op kunnen inspelen door de nodige voorzichtigheid aan de dag te leggen bij hun bemestings- en teeltpraktijken.

Versterkte handhaving voor een betere naleving

Uit de resultaten van de controleacties van de Mestbank blijkt dat de naleving van de mestwetgeving beter moet. Via risicogebaseerde bedrijfsdoorlichtingen worden probleembedrijven opgevolgd en gestuurd naar een gedragsverandering. "Bij 55% van de ruim 380 doorgelichte bedrijven in 2019 werden boetes, maatregelen of andere sancties opgelegd, naargelang de vaststelling. Een veel voorkomende vaststelling is het foutief aangeven van het kunstmestgebruik. De digitale registratie van kunstmest vanaf 2021 moet het reële kunstmestgebruik beter in kaart brengen", zegt Vlaams minister van Omgeving en Handhaving Zuhal Demir. Bij de mestverwerkingsinstallaties blijft de opvolging van de aan- en afvoerstromen naar en van de installaties een knelpunt, vandaar het belang van de verplichte installatie van bijkomende debietmeters op de mestverwerkingsinstallaties vanaf 2022.

"Uit de resultaten van de terreincontroles blijkt dat de aanwezigheid van de inspecteurs op het terrein effect heeft. Het verscherpte toezicht op de teeltvrije zone langs waterlopen zorgde voor een sterke daling van het aantal vaststellingen. De inbreukpercentages van de controleacties blijven evenwel nog steeds hoog en vereisen een sterke aanwezigheid van de inspecteurs op het terrein."

Bijkomende inspanningen nodig voor een verbetering van de waterkwaliteit

Vanaf 2021 geldt een nieuwe afbakening van de gebiedstypes waarbinnen gebiedsgerichte maatregelen genomen worden. Door de achteruitgang van de waterkwaliteit, neemt het areaal landbouwgrond in de gebiedstypes 1, 2 en 3, waar de waterkwaliteitsdoelstellingen nog niet behaald worden, toe van 60% tot 75%.

Daarnaast zijn bijkomende maatregelen nodig om op korte termijn een drastische verbetering van de waterkwaliteit te realiseren. Dat vereist een inspanning van alle betrokken actoren, in de eerste plaats de land- en tuinbouwers, maar ook de verwerkers, vervoerders, veevoederleveranciers, landbouwconsulenten, kunstmestproducten en -handelaars, veilingen, …. Vanaf 2021 zal de nieuwe 'Begeleidingsdienst voor Betere Bodem- en Waterkwaliteit' de land- en tuinbouwers ondersteunen bij het aanleren en toepassen van de beste en innovatieve landbouwpraktijken.

Retrieved on 7/12/2020 from https://pers.vlm.be/nog-te-veel-stikstof-in-het-water-in-landbouwgebied-door-verkeerde-bemestingspraktijken

Attachment 12: abbreviations

SDG	Sustainable Development Goals
UN	United Nations
N	Nitrogen
LDP	Land Development Project
VLAREM	Vlaams Regelement betreffende de Milieuvergunning
EU WFD	European Water Framework Directive
NVWG	Natuur VerWervings Gebied
NBS	Nature-Based Solutions
KMI	Koninklijk Meteorologisch Instituut
GL	Groundwater Level
VMM	Vlaamse Milieumaatschappij
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
VBS	Vegetative Buffer Strip
CMA	Compendium voor Monstername en Analyse
KLIP	Kabel en Leidingsinformatieportaal
PE	Polyethylene
EC	Electronic Conductivity
VLM	Vlaamse Landmaatschappij
WHO	World Health Organisation
PCM	Provincial Centre for Environmental Research